

THE BAT GROUNDWATER MONITORING
SYSTEM IN CONTAMINANT STUDIES

By

BARRY SHAUN MINES

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1992

Copyright 1992

by

Barry Shaun Mines

This dissertation is dedicated to my loving wife, Wendy,
who put many of her dreams on hold so that I might achieve one
of mine.

ACKNOWLEDGEMENTS

There are numerous individuals to whom I must express my gratitude for their help and guidance in my academic progression. It is definitely true that no man is an island as I have been significantly influenced by those around me.

Dr. Bloomquist has served as a technical consultant. By introducing high technology materials he has taught me to be innovative and to think like an inventor. He has also given me insight into many scientific principles.

Dr. Davidson has stressed to me the fundamentals of soil behavior. He has listened with keen interest to my progress reports after each field and laboratory test and has advised me well. My gratitude to him for reading and editing my research proposals and dissertation drafts are immeasurable.

Dr. Townsend has guided my professional development in several ways--first, by giving me numerous scientific articles dealing with my research which always seemed to come at an appropriate time. His teaching methods instilled in his students' confidence in their ability to design. Of all the teachers I have had he has stressed the practical aspects of design engineering, ensuring that students evaluate all possible concerns to come up with the most effective and economical designs. He has won me over to the teaching

profession through his sincere involvement in the students' development. He took groups to numerous construction sites to see engineering works firsthand and to seminars and conferences on new and innovative engineering techniques. As part of his involvement with the Engineers' Fair, he had students build reinforced earth walls with cardboard and paper strips, giving them the opportunity to work as a group on a engineering project as done in industry.

Charlie Schmidt enabled me to become a pseudo-chemist. He taught me the theory of mass spectrometry and allowed me hands-on use of the Gas Chromatograph/Mass Spectrometer for chemical analyses. He honed my skills as a chemist and gave me insight into the properties of hydrocarbons and chemical solvents.

Dr. Tom Stauffer provided technical assistance and arranged the financial support for this study. I am very appreciative of his promptness in reading my drafts and supplying helpful testing suggestions along with his hands on approach of going to the site to view the field testing.

I am deeply appreciative of Dr. Don Myhre's sincere interest in my project. He has always taken the time to listen to the progress of my research and to make helpful suggestions. From his soil chemistry class, he has stimulated my interest in the sorption capacities of soils and the partitioning of hydrophobic organic compounds.

Dr. Thompson and his staff have been most helpful in all administrative affairs, from working with the Air Force to obtain my funding, to ordering required equipment for my research. Dr. Thompson has always had time to discuss my research progress and provide liaison help with the Air Force. His seminar course has been on target with various speakers on current engineering issues. He has helped me to be a better engineer/manager by showing me that it is not enough to be a sound technical engineer; one must also be an informed citizen and be aware of changing current events and how they affect civil engineering.

My sincere appreciation is due to Ed Dobbson. Ed accompanied me on many BAT and electric cone penetration tests. He instructed me well on the use of the penetrometer rig to the point where I could manage on my own. Ed would always check to see when I would like to do more testing and was always most helpful. I could always count on Ed to help me fix any mechanical equipment with which I had problems. Ed, along with Dr. Bloomquist, was great at thinking of alternative ways to obtain groundwater samples.

I am grateful to the Handex Company, Geosolutions Inc., and the Alachua County Department of Environmental Control for letting me use their contaminated sites for this study.

To my brother, Dr. Richard Mines, I am grateful for his interest in my research. As a civil-environmental engineer,

he was responsible for introducing me to this area of study and for helping me develop into an engineer.

Richard and Dreama Mines, my parents, were responsible for instilling a high regard for education in my life. From my mother I have inherited an unquenchable desire for reading, which, along with my father's high level of motivation and determination, has allowed me to succeed in life. They taught me that if you don't push yourself in life, you will never know your limits.

I am most grateful to my wife, Wendy. She made several edits to my dissertation and allowed me to work numerous nights and weekends, sacrificing much of our time together. She was always there to help me when testing did not go well or equipment did not arrive.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	iv
LIST OF TABLES	xii
LIST OF FIGURES	xiv
ABSTRACT	xvi
CHAPTERS	
1 INTRODUCTION	1
1.1 Problem Statement	1
1.2 Objectives	3
2 REVIEW OF THE LITERATURE	5
2.1 Introduction	5
2.2 Direct Push Technology	6
2.2.1 Hydropunch	6
2.2.2 BAT Probe	9
2.3 DPT Field Studies	10
2.4 Sample Preservation	16
2.5 Necessity for Current Study	17
3 LAB PERMEABILITY TESTING	20
3.1 Permeability Limitations of the BAT System	20
3.2 Lab Permeability of Soils	22
4 BAT GROUNDWATER MONITORING SYSTEM LAB STUDIES	30
4.1 Introduction	30
4.2 Monitoring Well Model	31
4.3 Experiment 1 Inside Model Monitoring Well	33
4.4 Experiment 2 Inside the Model Monitoring Well	38
4.5 Experiment 3 Inside the Model Monitoring Well	41
4.6 Experiment 4--Sampling Within Tank Spiked Water	46
4.7 Experiment 5--Sampling Within Tank Spiked Water	51
4.8 Experiment 6--Sampling Within Tank Spiked Water	52

4.9	Teflon Ball and Tube Sampling Apparatus . .	54
4.10	BAT Vadose Zone Probe Testing	56
4.11	Summary	58
5	ANALYSIS, TRANSPORT, AND PROPERTIES OF VOLATILE ORGANIC COMPOUNDS	61
5.1	Introduction	61
5.2	Organic Compounds	61
5.3	Chemical Analysis	64
5.4	Regulatory Contaminant Levels	70
5.5	Solute Transport	71
6	FIELD STUDIES--CAVALIER PRODUCTS BUILDING SITE .	76
6.1	Introduction	76
6.2	Field Test 1	77
6.3	Field Test 2	79
6.4	BAT Sampling Within MW-17	84
6.5	CPT Testing	86
6.6	BAT Sampling Within MW-15	87
6.7	BAT Field Test 5	90
6.8	Summary	93
7	FIELD STUDIES--TEXTILE TOWN	94
7.1	Introduction	94
7.2	BAT Test 1	95
7.3	BAT Test 2	98
7.4	BAT Testing at MW-7	100
7.5	Vertical Contamination Profile at MW-7 .	103
7.6	Vertical Profile Testing at MW-11	104
7.7	BAT Probe testing in MW-11	107
7.8	Plume Chasing	109
7.9	CPT Testing	111
7.10	Summary	112
8	BAT MODIFICATION TESTING	114
8.1	Vacuum Pump Test 1	114
8.2	Vacuum Pump Test 2	118
8.3	Field Testing of Drill Rods as a Monitoring Well	122
8.4	Summary	124
9	CONCLUSIONS AND RECOMMENDATIONS	127
9.1	Conclusions	127
9.2	Recommendations for Future Testing . . .	130
9.3	Advantages of the BAT Groundwater Monitoring System	132

9.4	Disadvantages of the BAT Groundwater Monitoring System	133
-----	--	-----

APPENDICES

A	PERMEABILITY DATA	135
A.1	Needle Permeability Without Filter . . .	136
A.2	Permeability of Needle and HDPE Filter .	141
A.3	Permeability of Needle and Steel Filter .	146
A.4	Permeability of Kaolin-Sand Mixture . . .	158
A.5	Permeability of Yellow Fine Mortar Sand .	163
A.6	Permeability of a Uniform Sand	169
A.7	Permeability Data from Lynch Park	175
A.8	Sieve Analysis Data	177
A.9	Constant Head Permeability Data	178
A.10	Falling Head Permeability Test	179
A.11	Atterberg Limits	179
A.12	Derivation of Formulas for BAT Permeability Calculations	180
B	ORGANIC CHEMICAL DATA	187
C	BAT FIELD SAMPLING LOG	190
C.1	Cavalier Site	190
C.2	Textile Town Site	192
D	CHEMICAL ANALYSES DATA	198
D.1	GC/MS Data for Cavalier Site	198
D.2	GC/MS Data for Textile Town Site	200
E	DECONTAMINATION PROCEDURES	205
E.1	Bailer Decontamination	205
E.2	Decontamination of BAT Glass Sample Vials	205
E.3	BAT Probe Decontamination	206
E.4	Decontamination of Enviro probe	207
F	CONE PENETRATION DATA	208
F.1	CPT Sounding at Lynch Park Adjacent to MW-17	208
F.2	CPT Sounding at Lynch Park Adjacent to MW-15	208
F.3	CPT Sounding at Textile Town Around MW-11	209
F.4	CPT Sounding at Textile Town Around MW-7	209
G	HEADSPACE CORRECTIONS	210

H	OVERVIEW OF GROUNDWATER STRATEGIES	215
H.1	Groundwater Studies	215
H.1.1	Planning	215
H.1.2	Conventional Sampling Mechanisms	216
H.2	Monitoring Well Design Considerations	224
H.2.1	General	224
H.2.2	Monitoring Well Size	224
H.2.3	Expected Contaminants	225
H.2.4	Water Table Depth	225
H.2.5	Screen and Casing Materials	226
H.3	Well Development	229
H.4	Purging of Wells	230
H.5	Sampling Studies	231
H.5.1	Lab Studies	231
H.5.2	Field Studies	235
H.6	Underground Storage Tank Regulatory Programs	238
H.6.1	Congressional Acts	238
H.6.2	EPA's Underground Storage Tank Program	239
H.6.3	Florida DER Programs	242
	REFERENCE LIST	244
	SUPPLEMENTAL BIBLIOGRAPHY	251
	BIOGRAPHICAL SKETCH	255

LIST OF TABLES

Table 3.1 Permeability Limitation Values of BAT System	23
Table 3.2 Permeability of Three Soils	29
Table 4.1 Chemical Analyses of Sampling Within Model Monitoring Well	39
Table 4.2 Chemical Analyses of Experiment Two Inside the Model Monitoring Well	40
Table 4.3 Chemical Analyses of BAT Probe Sampling Inside the Model Monitoring Well	44
Table 4.4 Chemical Analyses of Sampling Within Tank Spiked Water	50
Table 4.5 Chemical Analyses from Sampling Within Tank Spiked Water	53
Table 4.6 Chemical Analyses of Experiment 6	55
Table 4.7 Vadose Probe Testing	59
Table 5.1 Henry's Constant for Selected VOCs	63
Table 5.2 Primary Drinking Water Standards (MCLs)	69
Table 5.3 Florida Ground Water Target Levels	71
Table 6.1 Chemical Analyses from MW-17 at Cavalier Site	81
Table 6.2 Chemical Analyses from MW-17 at Cavalier Site	83
Table 6.3 Chemical Analyses from BAT Sampling Within MW-17	86
Table 6.4 Chemical Analyses from BAT Sampling Within MW-15	89
Table 6.5 Chemical Analyses from Lab Insitu Class	92

Table 7.1 Chemical Analyses from MW-17 at Textile Town	103
Table 7.2 Chemical Analyses of Vertical Sampling at MW-7	105
Table 7.3 Analyses from BAT Testing in MW-11	110
Table 7.4 Chemical Analyses from Plume Chasing . . .	112
Table 8.1 Chemical Analyses from MW-7	119
Table 8.2 Total Times for Truck Set Up and Sampling .	120
Table 8.3 Chemical Analyses from Vacuum Pump Apparatus	121
Table 8.4 Chemical Analyses from BAT Testing around MW-7	125
Table 9.1 Summary Comparison of BAT Versus BAiler Recovery of VOCs	128
Table G.1 Henry's Law Constants for Selected Organic Compounds	212

LIST OF FIGURES

Figure 2.1 Hydropunch in Closed and Open Positions . .	8
Figure 2.2 BAT Enviroprobe in Closed and Open Positions	11
Figure 3.1 Gradation Curve of Uniform White Fine Sand .	25
Figure 3.2 Gradation Curve of Fine Mortar Sand	26
Figure 4.1 Teflon Bailer	32
Figure 4.2 Model Monitoring Well Set-Up	34
Figure 4.3 BAT MK2 Probe	36
Figure 4.4 Cascaded Sampling for Zero Head Space Sample	37
Figure 4.5 BAT Probe with Reaction Beam	43
Figure 4.6 Balloon and Test Tube Apparatus	47
Figure 4.7 BAT Sampling in Nalgene Container	48
Figure 4.8 Typical Soil Moisture Curve	60
Figure 5.1 Transport of a Typical LNAPL	62
Figure 5.2 Transport of a DNAPL	65
Figure 5.3 Typical Ion Chromatograph	67
Figure 5.4 Typical Mass Spectra	68
Figure 6.1 Cavalier Site Plan	77
Figure 6.2 View of Cavalier Site--Lynch Park on Left .	78
Figure 7.1 Textile Town Site Plan	95
Figure 7.2 View of Textile Town--Penetrometer Rig near MW-7	96

Figure 7.3 Cone over MW-11	97
Figure 7.4 View of Stripping Tower for Remediation .	101
Figure 7.5 Penetrometer Rig around MW-7	102
Figure 7.6 Vertical Contamination Profile at MW-7 . .	106
Figure 7.7 Vertical Contamination Profile at MW-11 .	108
Figure 7.8 Lateral Plume Delineation	113
Figure 8.1 Brass Adaptor for Vacuum Pump Testing . .	115
Figure G.1 Fraction Remaining C/C_0 versus V_g/V_s for Headspace Related Errors for Selected Aromatics. Compounds Apply to 20 °C . . .	213
Figure G.2 Fraction Remaining C/C_0 versus V_g/V_s for Headspace Related Errors for Selected Chlorinated Compounds. Compounds Apply to 20 °C	214
Figure H.1 Conventional Groundwater Sampling Mechanisms	218

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

THE BAT GROUNDWATER MONITORING SYSTEM IN
CONTAMINANT STUDIES

By

Barry Shaun Mines

August 1992

Chairperson: John L. Davidson
Major Department: Civil Engineering

Groundwater contamination continues to be a serious threat to our environment. One prevalent cause of such contamination is leakage from underground storage tanks. Detection and assessment of contamination must be made before remediation of any site can begin. This is traditionally accomplished by sampling from monitoring wells. The BAT Groundwater Monitoring System is a recently developed device which can collect samples of pore fluid without the need for a drilled well.

An experimental study was conducted on the BAT System, with the major objective of evaluating its effectiveness in sampling volatile organic compounds (VOCs). Both large-scale laboratory and field investigations were carried out. At many locations BAT testing was compared to adjacent bailer sampling from monitoring wells.

Neither the well bailer nor the BAT system consistently recovered more VOCs, though concentrations recovered in most cases were comparable. BAT samples recovered using a stainless steel filter element consistently exhibited higher concentrations of VOCs than did samples from probes with the HDPE filter. Concentrations of volatile constituents in BAT samples displayed a lower standard deviation than did samples obtained using the bailer.

The effect of headspace in the BAT's sampling tubes was investigated. VOCs measured in single tubes with small amounts of headspace compared favorably with those in test tubes obtained in a cascaded set-up which had no headspace. The use of an inert material balloon within the sampling tube to eliminate headspace and vacuum effects showed promise. Modifications to the equipment were made to investigate the possibility of drawing the much larger fluid samples required for some chemical tests.

The BAT System can be used to estimate a formation's coefficient of permeability. It was found that this capability is limited, by the pore size of the filter element, to determinations in very fine material, specifically silts and clays.

The BAT test is a relatively rapid, inexpensive penetration test which provides high quality and reproducible pore fluid samples. It has the potential for use in the assessment of contaminated sites, especially in the

delineation of leakage plumes and in siting of permanent wells.

CHAPTER 1 INTRODUCTION

1.1 Problem Statement

Groundwater contamination continues to be a serious threat to our environment at a time when the demand for water resources has never been greater. Many states, including Florida, obtain the majority of their water from groundwater (aquifers). Contamination of this water can occur from numerous sources. Some of the more prevalent are the application of pesticides for agricultural uses, leakage of fuel from storage tanks (above or below ground), leakage of leachate from sanitary landfills or hazardous waste sites, and spillage/leakage from industrial plants. For, example the Florida Department of Environmental Regulation (Stuart, 1986) estimates that 6000 of the state's 60,000 petroleum storage tanks are leaking. Currently there are over 1.4 million underground storage tanks in the United States that are regulated by the Resource Conservation and Recovery ACT (RCRA). Of these it is estimated that approximately 80% are constructed of bare steel, which is easily corroded.

Determination of the presence of groundwater contamination is typically performed by installing monitoring

wells for groundwater sampling. Alternative methods include soil sampling for analysis, extraction of vapors from the vadose zone, magnetic/resistivity surveys, and direct push (or penetration) technology (DPT).

DPT makes use of a cone device which is pushed or hammered into the ground. Some tips have sensors for measuring the changes in the resistivity/conductivity of the soil which can provide a measure of the total dissolved solids through correlations. Others tips use fluorescence sensors to detect contamination (Cooper and Malone, 1991). Fluorescence sensors radiate ultraviolet light out into the soil where some contaminants absorb the radiation and then fluoresce (emit light). The emitted light is received by a fiber-optic link which sends the information to an optical analyzer for spectral analysis. Cooper and Malone (1991) state that these sensors are only good for contamination concentrations greater than 200 ppm. Another problem with this system is that not all organic compounds fluoresce. Some that do are polynuclear aromatic hydrocarbons (PAHs), phenol, toluene, and the xylenes. Naturally occurring materials also fluoresce causing interference.

A relatively new penetrometer, the BAT probe (Torstensson, 1984), allows groundwater samples to be taken without installation of costly monitoring wells. A porous element in the probe's tip connects via a hypodermic needle and septum with an evacuated sample tube, which is lowered

down the center of the push rods from the surface. However, considerable doubt has existed in the regulatory arena as to whether such a sampling device would cause a loss of VOCs due to the initial vacuum in the sample tube. Some environmental regulatory agencies are not willing to use the BAT until a larger data base has been established on its ability to obtain a representative sample. Peristaltic pumps used to obtain groundwater samples from monitoring wells have generally been ineffective for sampling VOCs because the reduced pressure causes the VOCs to volatilize away.

The question to be answered is whether the BAT probe can be penetrated into the ground and recover groundwater samples which contain contamination levels comparable as that obtained using a monitoring well and bailer.

1.2 Objectives

The purpose of this study is to provide an in-depth, comprehensive study to compare results from the BAT probe and and Teflon bailers from nearby monitoring wells. VOCs are typically the most difficult contaminants to sample. The research was performed by taking samples within a small radius around monitoring wells at two leaking underground storage tank sites and taking bailer samples from the monitoring wells. BAT sampling will also be performed inside the monitoring wells to ensure basically the same water is being sampled.

A secondary purpose of the study is to evaluate the repeatability of BAT probe testing, i.e., what is the precision of the device? Does it have a high or a low standard deviation compared to the Teflon bailer? Other objectives of the research are to:

1. Evaluate the significance of headspace in BAT sample vials and look at possible modifications to eliminate this headspace.
2. Perform laboratory testing to determine the limitations of the BAT probe for the determination of the coefficient of permeability. Does the BAT probe give reasonable values of the coefficient of permeability?
3. Examine modifications which could be made to the BAT groundwater monitoring system to allow collection of larger sample sizes.
4. Perform BAT testing to determine the extent of vertical and horizontal contamination at a site.
5. Determine typical sampling times for the BAT probe along with time estimates for setting up a penetrometer rig and taking groundwater samples with the BAT probe.
6. Provide an overall evaluation of the BAT system, its advantages, disadvantages, and uses in groundwater studies (specifically contamination assessments).
7. Recommend future possible research with the BAT system.

CHAPTER 2 REVIEW OF THE LITERATURE

2.1 Introduction

The ability to characterize the quality of groundwater adequately and economically is a major concern in all contamination studies. In order to determine whether a site's groundwater is contaminated, samples must be obtained for chemical analysis to verify the presence of contaminants and their concentrations. Engineers, owners, contractors, and regulatory officials are concerned with obtaining groundwater samples that are "representative" of actual insitu conditions. Obtaining "representative" groundwater samples for chemical analysis is extremely difficult, if not impossible. It parallels the problem geotechnical engineers have in obtaining "undisturbed" soil samples.

The literature review that follows first gives descriptions of two DPT systems (BAT System and the Hydropunch) used for performing groundwater contamination assessment and then presents a critical review of previous testing of these devices. Lastly, a discussion of headspace in sample vials is presented.

2.2 Direct Push Technology

Development of DPT within the past ten years has made it possible to take groundwater samples without having to drill and install a monitoring well. This is a significant breakthrough since Pettyjohn et al. (1981) have shown that drilling monitoring wells can alter the chemical and microbial environment in the vicinity of the well. Drilling fluids can especially alter the chemistry of the groundwater. Direct push technology has been around for decades in the form of cone penetration testing. Cone penetration testing is used to determine soil stratigraphy by measuring the end bearing and frictional resistance on a tip of standard dimensions, which is pushed into the ground at a standard rate. ASTM D3441 governs the performance of the test. In DPT a sampling device is attached to a string of drill rods and either hammered or hydraulically pushed into the ground to the required sampling depth. Two such commercial devices which will be discussed below are the Hydropunch and the BAT Groundwater Monitoring System.

2.2.1 Hydropunch

The Hydropunch device was introduced in March 1985. Edge and Cordry (1989) give an excellent overview of the system. The device has a stainless steel drive cone, a stainless steel perforated intake for sampling, and a stainless steel sample chamber. To obtain a sample, the device is attached by means

of an adapter to either cone penetration rods or drill rods. The device is pushed hydraulically to the required sampling depth. The push rods are then pulled up 1.5 feet to expose the stainless steel intake. The drive cone is held in place by the friction of the soil. Once the intake is exposed, water flows through the intake into the sample chamber due to hydrostatic pressure. Once the chamber is filled (5 mL) the device is pulled to the surface. A ball valve, similar to that in a bailer, closes during extraction ensuring no loss of sample. At the surface the device is disassembled and a discharge tube inserted into the unit to allow transfer of the fluid sample to a container for storage and transport to a lab. Figure 2.1 is a diagram showing the Hydropunch operation.

The device minimizes cross contamination. Since the exterior of the device is smooth, contaminated soil is not transported down as the sampler is advanced. It also has the advantage of not exposing the sample to negative pressures which could cause degassing and loss of VOCs. It has the disadvantage of only obtaining a very small sample (5 mL). In sandy soils, samples can be obtained in as little as 5 minutes. In clayey soils it may take 45 minutes or longer. Like the bailer, the sample must be transferred to a sample container, a process which could cause loss of VOCs. The hydropunch requires no purging of water as is necessary in the use of monitoring wells.

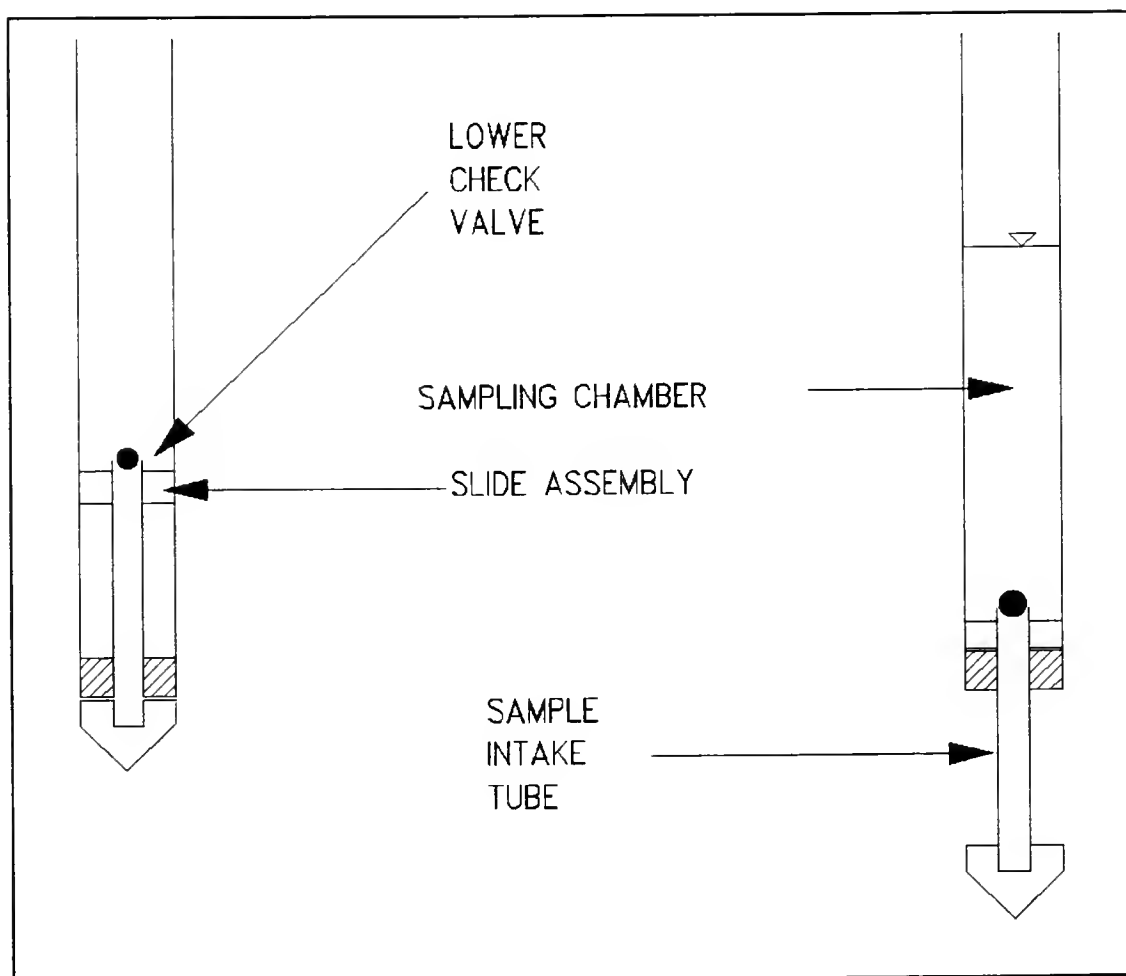


Figure 2.1 Hydropunch in Closed and Open Positions

2.2.2 BAT Probe

Torstensson (1984) describes another probe that was developed for groundwater sampling using DPT. The standard device, known as a BAT probe, consists of a tip with a porous filter. The probe is attached to special drill rods (1 inch minimum inner diameter) and then pushed hydraulically into the ground to the required sampling depth. At the ground surface, a vacuum pump is used to evacuate a test tube (35 mL) which is placed within a housing. A chain of weights is attached to the housing and to a steel cable, which is used to lower the apparatus through the center of the drill rods. The housing also contains a double-ended needle, which is installed within a spring. Once the housing reaches the bottom of the drill rod, the hypodermic needle first makes contact with a septum in the BAT probe and is then pushed up through a septum in the test tube. Water is thus drawn through the porous filter of the BAT probe and into the evacuated test tube. When equilibrium is reached the apparatus is manually pulled to the surface and the test tube removed from the housing, labeled, and placed in a cooler for transport to a laboratory. When pulling up on the steel cable, the spring in the housing causes the double-ended needle to simultaneously lose contact with the test tube and the septum of the filter, ensuring no sample loss. The BAT system has other attachments which can be lowered down the drill rods to measure pore water pressure and to perform hydraulic conductivity tests. Torstensson

(1984) describes the use of the system in monitoring Cl^- concentrations with depth and with time at a Stockholm, Sweden, site in 1981. Figure 2.2 shows a diagram of the BAT Enviroprobe.

2.3 DPT Field Studies

Edge and Cordry (1989) discuss several case histories in which the Hydropunch was used in groundwater contamination studies. It was used in 1985, 1986, and 1987 at a California landfill for the detection of leaking, low level, VOCs. At a schoolyard in the spring of 1986 in Los Angeles, California, it was used on a weekend to confirm the presence of benzene, toluene, and xylene contamination. The study was carried out over the weekend to minimize disruption to the school and was completed at a third of the cost of monitoring wells. In 1988, it was used at a petrochemical facility in Louisiana to detect low levels of chlorinated organics. The concentration and extent of contamination was determined which allowed planning of remedial measures. Klopp et al. (1989) discuss several case histories of the use of the BAT system in groundwater contamination studies. It was used to study the stratification of arsenic near San Francisco in 1986. It was also used for several projects in Texas under the review of the USEPA and the Texas Water Commission. These included sampling at a leaking storage tank, delineation of a plume,

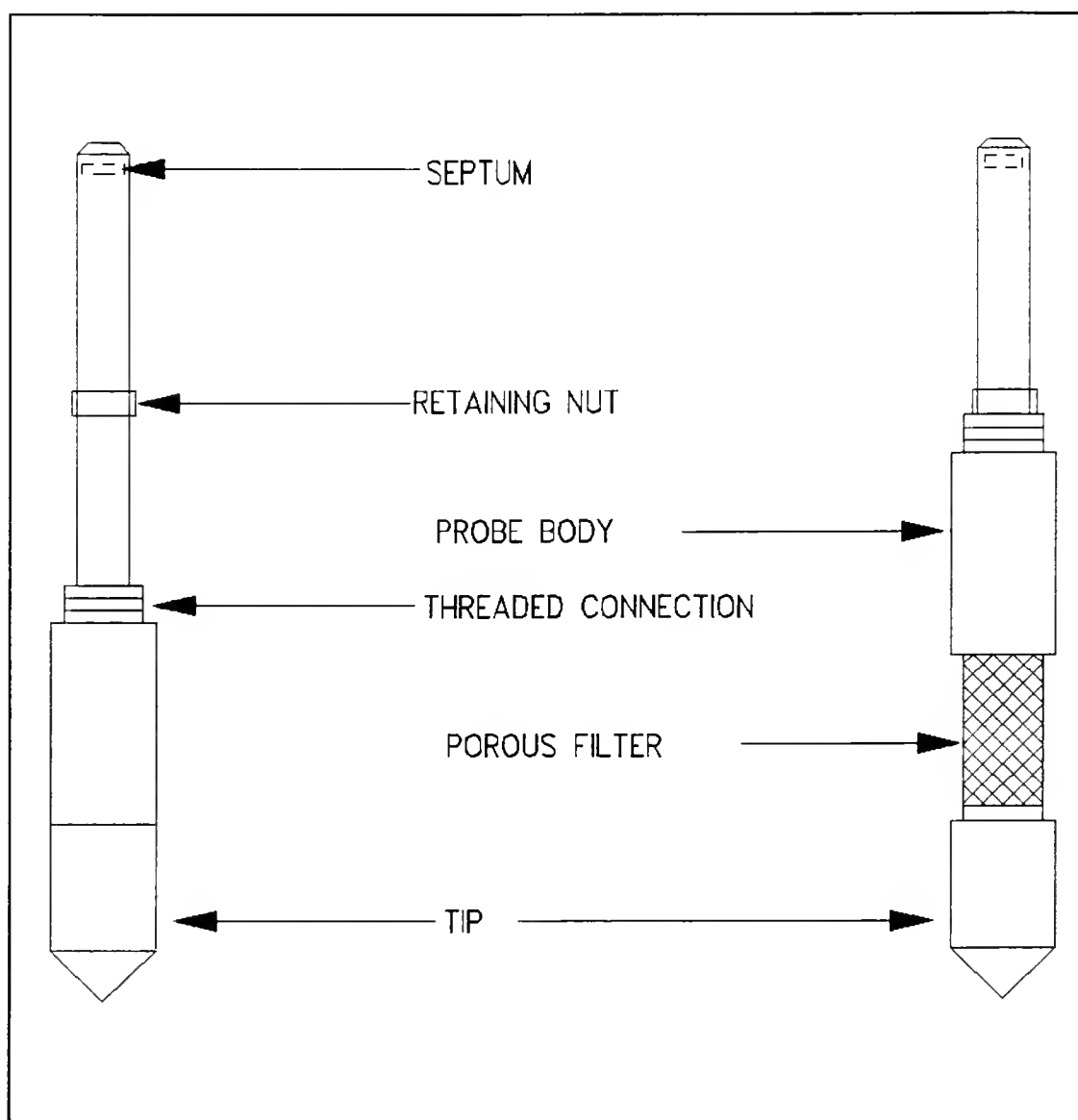


Figure 2.2 BAT Enviroprobe in Closed and Open Positions

detection of buried hazardous waste, and sampling at an abandoned land fill. This paper notes that the BAT system can take a sample at one elevation, be decontaminated at that elevation, then pushed to another depth for additional sampling in order to vertically delineate the ground water quality.

Smolley and Kappmeyer (1991) used the Hydropunch at Silicon Valley, California for the plume delineation of VOCs that had leaked from underground storage tanks. The Hydropunch was first validated by pushing it beside an existing monitoring well and taking ground samples from each for comparison. The Hydropunch gave higher concentrations of VOCs than samples from the monitoring well. The operators of the Hydropunch only had a 70% sample collection success rate at this site. They found that the check valve does not always close properly, causing a loss of sample. The study concluded that by using the Hydropunch samples could be collected at 20 to 40 percent of the projected cost of monitoring wells. The work was also completed in a third of the time that would have been required for monitoring wells. This paper states that samples up to 500 mL can be taken with the sampler, which is significantly larger than that stated by Edge and Cordry (1989). This must be due to some modification to the system.

Strutynsky and Sainey (1990) discuss the use of both the Hydropunch and the BAT system at an industrial site in southern Ohio to delineate a trichloroethene plume. These

systems were chosen because the plume had moved off the manufacturer's site onto the property of a farmer who did not want monitoring wells installed on his property. At this site the operators had an 81% sampling success rate with the Hydropunch (22 samples out of 27 attempts). It was noted that the tip had to be placed at least 4 feet below the water table for sample collection. The BAT system was tried at two locations at this site. The first was not successful as the thin walled casing used to push the BAT probe buckled. Normally, heavy duty steel drill rods are used to push the BAT probe. At the second location the BAT Enviroprobe was successful in obtaining multiple samples.

Lammons et al. (1991) discuss the use of the Hydropunch at an industrial site in South Carolina to delineate the vertical and horizontal extent of ground water contamination. The Hydropunch took samples at several locations which were then made into permanent monitoring wells. The Hydropunch was able to take a significantly greater number of samples than conventional methods for the same cost, which made it possible to more effectively delineate the contaminant plume.

Torstensson and Petsonk (1988) discuss the work done by the Earth Technology Corporation at two contaminated sites in California. At one site samples were taken from a monitoring well with a conventional teflon bailer. The BAT probe was then placed inside the well and additional samples taken. The samples were analyzed by EPA methods 601 and 602. The BAT

samples showed consistently higher concentrations of VOCs. For one contaminant, tetrachloroethene, the BAT probe recovered 77% more than the bailer did. The actual concentrations of contaminants were probably even greater than obtained with the BAT probe, as the 35 mL sample vials had a slight headspace in them. Torstensson suggested that two sample vials could be used in conjunction to avoid having any headspace. Two test tubes would be placed in a sample housing with a hypodermic needle between them. During sampling, the bottom test tube would fill completely with the overflow going up into the second test tube. Therefore the second test tube would contain water and headspace while the bottom one would be completely filled.

Geomatrix Consultants (1986) used the BAT probe at East Palo Alto, California, to delineate an arsenic plume. Fourteen BAT soundings were made to determine the concentration of arsenic with depth. Samples obtained from the BAT system were in general agreement with those obtained from the few monitoring wells that were already in place.

The BAT probe can also be used for vadose zone monitoring as demonstrated by Haldorsen et al. (1985). A sintered ceramic filter with an average pore size of 2 microns is used. Since initially a vacuum is placed on a test tube, this device can only obtain a ground water sample when the soil tension is less than about 10 meters of water. By measuring the pore pressure changes with time as the water flows into the

sampler, the unsaturated hydraulic conductivity can be calculated. The saturated hydraulic conductivity in an unsaturated zone can be determined by performing an outflow test while measuring pore pressure changes with time. This is done by partially filling a test tube with water and then pressurizing it. The water is forced into the unsaturated zone and gradually saturates the soil. In a fairly homogeneous soil the probe can be used at different depths, each having a different soil tension, to obtain the hydraulic conductivity which can be used to plot the $K(h)$ curve. Peterson (1985) discusses the theory for performing hydraulic conductivity tests which is based upon work by Hvorslev, Dachler, and from Boyle's Law.

A large scale field comparison of several ground water sampling devices was performed at the Desert Research Institute in Las Vegas, Nevada, in conjunction with the USEPA Environmental Monitoring Systems Laboratory (Blegen et al., 1988). The sampling devices used in the comparison included a teflon bailer, a bladder pump (Well Wizard), the West Bay MP System, two in situ BAT probes, and a BAT well probe. Six "monitoring" wells were installed at a site contaminated with benzene and chlorobenzene. Three wells were of the conventional type. Two others were constructed by drilling a borehole, inserting a BAT probe into it, placing a gravel pack around the probe, and backfilling the borehole. The last well was a borehole in which the Westbay MP system was installed.

The wells were set up in a rectangular grid with a 20 foot spacing between them. Samples were taken with each device over an eight week period. The bladder pump and the BAT probe generally obtained the highest recovery of organics; the Westbay system obtained the lowest, with the teflon bailer in between.

2.4 Sample Preservation

Johnson et al. (1987) looked at the effect of headspace in sample bottles on the loss of VOCs. They found that if the volume of the headspace is greater than 5% of the total volume of the container, significant loss of VOCs could occur. In one instance, a sample bottle only half filled with a sample had a 50% reduction in 1,1,1-trichloroethane.

Pankow (1986) also studied the effect of headspace on the loss of VOCs. He provides an excellent table and figure relating the loss of VOCs to different headspace volumes for numerous organic chemical compounds. Appendix G provides expanded figures of the concentration remaining in solution versus different headspace volumes for selected aromatic and chlorinated organic compounds. He found that samples containing benzene and toluene and with a ratio of volume of headspace to volume of sample as great as .1 only suffered a compound loss of 1%. However, with some other organics, such as vinyl chloride and chloroethane, a .1 ratio of headspace to

sample would result in a loss of 25% or more. The effect of headspace is thus very dependent upon the contaminant in question.

Clesceri et al. (1989) recommend that sample vials for volatile analysis have no headspace to avoid loss of volatiles by volatilization. Samples once taken in the field should be placed in a cooler supplied with ice packs to maintain the temperature at 4°C. By keeping the samples cool and dark there is less chance of loss of volatiles and less chance of growth of microorganisms.

2.5 Necessity for Current Study

Blegen et al. (1988) performed a study comparing seven different samplers, including the BAT groundwater monitoring system and a Teflon bailer, at a single site in Nevada. Several issues were not addressed in this study. At no time were BAT and Teflon bailer samples obtained from the same monitoring well to be sure that basically the same water was being sampled. In this study, a hole was predrilled, the BAT probe installed, and the hole then backfilled with a gravel pack, fine silica sand, and a cement-bentonite slurry. The BAT probe in this case was basically an installed monitoring well. This defeats the major purpose of the BAT, which is to eliminate drilling and installation of a monitoring well. The question is whether the BAT can be penetrated into the ground and recover representative samples which contain contamination

comparable to that obtained using a monitoring well and bailer.

In Blegen's study the BAT probe was installed 20 feet from the monitoring well where Teflon bailer samples were obtained. Such a significant distance in itself may cause a discrepancy in the concentrations of contaminants measured. Variations can also be caused by the sampling depth interval. The BAT groundwater monitoring system samples over a length of 2 inches while the wells installed were screened over a 12 inch interval. No information in their study is given as to whether or not BAT samples were obtained using cascaded sampling techniques to eliminate headspace. No data was presented where the BAT probe was used with a stainless steel filter in comparison to a HDPE filter.

The current study is needed to develop a larger database with the BAT groundwater monitoring system. Numerous regulatory agencies are skeptical of new and innovative systems until they are thoroughly tested to validate their use. This study will provide sampling with the BAT probe using both steel and HDPE filters to evaluate the better of the two. BAT sampling will be performed inside monitoring wells to allow comparison directly with Teflon bailer samples to validate its ability to recover VOCs. BAT sampling will also be performed adjacent to monitoring wells to show that it can recover higher concentrations of VOCs than the teflon bailer in monitoring wells due to the dilution effect which

can occur in monitoring wells. Statistics will be given to show that the BAT system is a more precise device by showing a lower standard deviation and relative standard deviation (coefficient of variation) than the bailer.

BAT samples will be analyzed at different amounts of headspace to see if significant losses of VOCs occur in the BAT sample tubes due to headspace. Pankow (1986) has previously shown that losses of BTEX in sample vials with small amounts of headspace was minimal.

CHAPTER 3 LAB PERMEABILITY TESTING

3.1 Permeability Limitations of the BAT System

The insitu coefficient of permeability can be determined using the BAT groundwater monitoring system. Both inflow and outflow testing is possible. For inflow testing the BAT MK2 probe is hydraulically pushed to the desired depth. The pore water pressure is determined by using the BAT pore water pressure adaptor. The adaptor uses a single ended hypodermic needle to make hydraulic connection between the BAT probe and a pore pressure transducer which is connected to a digital display unit. The insitu pore pressure is recorded from the hand held display unit. A double ended test tube is then placed in a housing and is connected to the pressure transducer by means of a single ended hypodermic needle which is connected to an extension cylinder. The extension cylinder has a small port which contains a rubber septum. For inflow testing a needle is used to pierce the septum and either a syringe or vacuum pump is used to evacuate the test tube. For outflow testing, water is placed into the test tube and then pressurized using a syringe through the septum port. The pressure in the test tube can be read on the display unit.

Once the desired pressure is attained the needle is removed from the septum and the test tube remains sealed at that pressure. The housing is then lowered down the drill rods until connection is made with the probe. Upon connection a stopwatch is started. Pressure readings should be taken from the hand held digital read-out at regular intervals. In the inflow test, as water is drawn into the test tube the pressure becomes more positive. The initial pore pressure reading along with the pressure readings with time are input into a computer program "Perm" Version 13 developed by the BAT company which calculates the coefficient of permeability. Additional information on the program "Perm" is provided in section A.12 of Appendix A.

In both the inflow and outflow tests water must pass through the probe's porous filter and through the hypodermic needle which provides connection between the sample tube and the probe. It is apparent that there will be a maximum soil permeability which can be correctly measured. In a more permeable soil the flow of water will be governed not by the soil but by the filter and/or the needle. The determined "permeability" will be of the device and not of the penetrated soil. This limiting permeability value was determined by laboratory testing.

The BAT probe was placed in a bucket of water and inflow permeability testing performed. An initial vacuum (negative pressure) was applied to the test tube using a vacuum hand

pump. The test tube was then lowered down the drill rods until needle contact was made with the probe's septum. Because the test tube pressure was lower than the insitu (bucket) water pressure, water was drawn into the tube. This continued until equilibrium was reached, i.e., the pressure in the test tube was equal to the external water pressure.

Twelve tests were performed using the stainless steel porous filter and five using the high density polyethylene (HDPE) porous filter. To determine if the porous filter or the needle actually provided the limiting permeability, five additional tests were performed with no porous filter. The results are shown in Table 3.1. The average permeability of the set-up using the steel filter was $7.8\text{E-}04$ cm/sec, using the HDPE filter $1.7\text{E-}04$ and with no filter $6.1\text{E-}03$. This demonstrates that it is the pore size of the probe filter which is the limiting component.

The BAT groundwater monitoring system with the porous filters tested is not suitable for permeability testing in soils with a coefficient greater than approximately $1.0\text{E-}04$ cm/sec, i.e., clean sands and sand-gravel mixes. The methods may be suitable in such soils as clays, silts, and clay or silt-sand mixes (Cedergren, 1977).

3.2 Lab Permeability of Soils

The coefficients of permeability of three soils were determined in the laboratory using the BAT groundwater

Table 3.1 Permeability Limitation Values of BAT System

TRIAL	PERM W/STEEL FILTER (cm/sec)	PERM W/HDPE FILTER (cm/sec)	PERM NO FILTER (cm/sec)
1	9.6E-05	1.4E-04	5.0E-04
2	4.6E-04	1.6E-04	8.2E-03
3	4.1E-03	1.4E-04	2.1E-02
4	2.4E-03	1.5E-04	6.2E-05
5	6.2E-04	2.4E-04	7.2E-04
6	1.1E-04		
7	1.1E-03		
8	9.6E-05		
9	8.3E-05		
10	8.5E-05		
11	9.0E-05		
12	7.2E-05		
AVERAGE	7.8E-04	1.7E-04	6.1E-03
STD DEV	1.2E-03	3.4E-05	7.3E-03

monitoring system and then compared with values obtained from constant/falling head tests. The soils were a uniform white silica sand, a fine yellow mortar sand, and a 50% silica sand-50% kaolinite clay mixture. The uniform white silica sand was obtained from the Feldspar Corporation of Edgar, Florida (EPK Sand, CAS NO. 14808-60-7). It had an effective size (D_{10}) of .16 mm, a uniformity coefficient (C_u) of 1.7 and a coefficient of curvature (C_z) of .93. Its grain size distribution curve is shown in Figure 3.1. This soil also classified as an A-3 according to the AASHTO system. The fine yellow mortar sand (Figure 3.2) had a D_{10} of .19 mm, a C_u of 1.7 and a C_z of 1.08. This soil classified as an A-3 in the

AASHTO system. Both soils classified as a SP (poorly graded sand) according to the Unified Soil Classification System (USCS). The sand-clay mixture was obtained by blending the EPK sand with pulverized kaolin that was also obtained from the Feldspar Corporation (CAS No. 1332-58-7). The mixture had a plastic limit of 20.0 and a liquid limit of 31.8. Coefficients of permeabilities of the sands were also estimated using Hazen's equation:

$$k = C * (D_{10})^2$$

where k = permeability in cm/sec

C = empirical factor with an average value of 1

D_{10} = effective diameter in mm

Hazen estimates are included in the table of results, Table 3.2

Before performing any BAT permeability testing in the lab it was necessary to determine the size of container (bucket) which would avoid any boundary effects that could influence the results. Drawdown was estimated by assuming a porosity of the sand, knowing the radius of the available containers and knowing the volume of water which would be removed per test (35 mL).

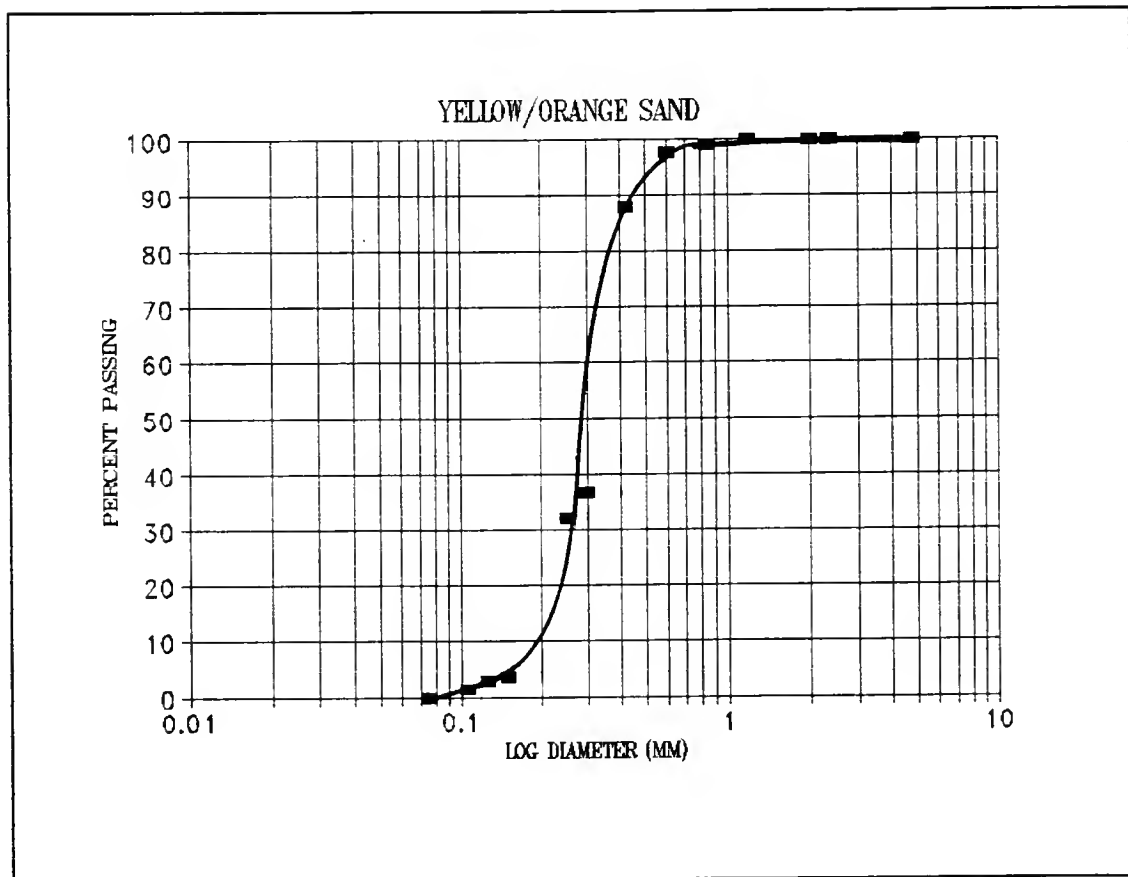


Figure 3.2 Gradation Curve of Fine Mortar Sand

$$H-h_w = \frac{35}{\pi * 14^2 * .3} = .19 \text{ cm} = .00623 \text{ ft}$$

To determine the upper limit of the coefficient of permeability that could be used with this bucket the following equation was used (Joint Technical Manual Departments of the Army, Air Force, and Navy, 1983):

$$R = C * (H - h_w) * \sqrt{K}$$

where R = radius of influence in feet

H = height of water level beyond the zone of influence

h_w = height of water at the probe

$H - h_w$ = the drawdown in feet

C = empirical factor normally equal to 2 or 3

k = coefficient of permeability in units of 10^{-4} cm/sec

$$\frac{5.5}{12} = 3 * .00623 * \sqrt{K}$$

$$K = 6.01 * 10^{-2} \frac{cm}{sec}$$

This coefficient of permeability is significantly greater than the upper limit of the BAT system ($1.0E-04$ cm/sec). The 11 inch diameter bucket is therefore satisfactory as regards to boundary affects.

The experiments with the sand consisted of placing a known volume of water into the bucket, locating the BAT probe in the center of the bucket and raining a known amount of dry sand (by weight) in around it. The bucket was shaken to vibrate and settle the soil thereby eliminating any large voids. This procedure was followed until the bucket was filled with sand (an approximate height of 13 inches) and the water level was at the surface of the sand. This allowed the exact water pressure and the unit weight of the material to be known. The pore pressure was also checked with the BAT pore

pressure device. This gave water heights within 2 cm of the known heights in the bucket. Since the steel filter had the highest permeability it was used for all testing.

For the BAT permeability testing the white silica sand had a dry unit weight of 80.6 pcf and a moist (saturated) unit weight of 109 pcf. The yellow mortar sand had a dry unit weight of 90.6 pcf and a moist unit weight of 114.4 pcf. The same respective dry unit weights were used in the constant head tests.

The sand-kaolin mixture was prepared by placing a known amount of water into the bucket and adding a known dry amount of kaolin. The water and kaolin were mechanically mixed. Sand was mixed in gradually until a 50-50 mixture of sand-kaolin had been made. The mixture had a dry unit weight of 67.5 pcf and a moist unit weight of 99.3 pcf. The moist unit weight in the falling head test was 118 pcf.

The results of the permeability testing are shown in Table 3.2. The kaolin-water mixture had the lowest coefficient of permeability of the three soils as expected. The BAT underestimated the coefficient of permeability by a factor of 100 when compared with the falling head test even though the material was in a denser state in the falling head apparatus. The permeabilities' calculated using Hazen's equation for the sands compared rather well with the values obtained from the constant head permeability tests. Values obtained with the BAT probe did not compare well with the

constant head tests. It was evident that the fine sands were more permeable than the steel filter used on the BAT probe. The BAT testing in the fine sands was still a measure of the permeability of the steel filter and not of the fine sand. It is evident that the BAT is severely limited for permeability testing. Further research could include comparison of the coefficient of permeability from the BAT probe and from field pumping tests since both measure predominantly the horizontal coefficient of permeability.

Table 3.2 Permeability of Three Soils

TRIAL	PERM SAND-KAOLIN (cm/sec)	PERM FINE MORTAR SAND (cm/sec)	PERM UNIFORM SAND (cm/sec)
1	2.8E-07	4.2E-04	1.8E-05
2	2.1E-07	6.5E-04	2.0E-05
3	2.0E-07	5.9E-05	1.3E-05
4	2.0E-07	9.6E-05	7.4E-05
5	2.0E-07	5.3E-04	5.3E-05
6		2.6E-05	5.8E-05
AVERAGE	2.2E-07	3.0E-04	3.9E-05
STD DEV	2.9E-08	2.3E-04	2.2E-05
HAZEN'S EQ		3.6E-02	2.6E-02
CONSTANT HEAD	-	2.3E-02	1.6E-02
FALLING HEAD	6.3E-05	-	-

CHAPTER 4 BAT GROUNDWATER MONITORING SYSTEM LAB STUDIES

4.1 Introduction

This chapter discusses laboratory studies which were performed to evaluate the BAT probe's ability to recover VOCs as compared to that of the Teflon bailer in a controlled environment. A model monitoring well was built to sample with the BAT probe and with the Teflon bailer. Additional testing with the BAT probe and the bailer was performed in a large nalgene tank filled with water spiked with gasoline constituents. This testing was performed to directly compare the amount of VOCs recovered from the BAT probe and the Teflon bailer to determine if the BAT performed comparable to the bailer.

Each section describes in detail all set-up procedures and testing sequences. All chemical analyses for this study (both laboratory and field) were performed on a Gas Chromatograph/Mass Spectrometer (GC/MS) in accordance with EPA Methods 524/624 which allows water sample storage at 4 °C without preservatives up to seven days. The equipment used was a Hewlett-Packard 5985 GC/MS "benchtop" system with an HP 5840A gas chromatograph. The GC had a 30 meter capillary

column with a 0.32 mm inner diameter. Samples were purged for 11 minutes, desorbed for four minutes, and baked for 6 minutes.

Other topics include modifications of the BAT system to provide samples with no headspace including the use of balloons inside test tubes and Teflon tubes with Teflon balls. A BAT probe with a ceramic filter is used in the laboratory to simulate vadose zone testing.

4.2 Monitoring Well Model

A ground water monitoring well was constructed in the lab to model a typical field installation. The purpose of the model was to allow an evaluation of two types of groundwater sampling mechanisms, a Teflon bailer (350 mL--Norwell Company) and the BAT probe. The Teflon bailer is shown in Figure 4.1.

The model was constructed within a metal 55-gallon drum which was lined with a plastic nalgene container. The nalgene container was used to decrease the chemical interaction (sorption or leaching) that could occur between the contaminants and either the metal drum or regular plastic garbage cans. Because of the flexibility of the nalgene container the metal drum was needed to provide rigid containment. Since the nalgene tank had a flow valve on the bottom, a small slit was made down the side of the metal drum with a welding torch to allow its insertion. The monitoring

well was constructed of a 2.5 foot section of "triloc" slotted pvc well screen with a #10 slot (.01 inch opening). This was threaded onto a 2.5 foot section of pvc casing on one end and a pointed tip on the other. The monitoring well had an inner diameter of 2 inches. A uniform sand with an effective diameter of .012 inches was rained in around the monitoring



Figure 4.1 Teflon Bailer

well. Figure 4.2 is a photograph of the model monitoring well set-up.

4.3 Experiment 1 Inside Model Monitoring Well

In the first experiment a solution was prepared by mixing 50 liters of water with benzene, toluene, and o-xylene, each at a concentration of 20 $\mu\text{g/l}$ (20 ppb). This contaminated water was then siphoned through a flexible tube into the bottom of the monitoring well, from which it spread radially into the sand-filled container. Filling took approximately two and a half hours.

Several attempts to mix the chemicals directly with water were unsuccessful due to the relative insolubility of these volatile aromatics. Each attempt only provided a non-aqueous phase liquid (NAPL) above the water due to its lower specific gravity and hydrophobic characteristics. To overcome this problem 0.5 grams of benzene, toluene, and o-xylene were added to 50 ml of methanol (CH_3OH) to dissolve the aromatics. This provided a solution with a concentration of 10,000 mg/l (ppm).

$$\frac{.5\text{g}}{50\text{mL}} \times \frac{10^3\text{mL}}{\text{L}} \times \frac{10^3\text{mg}}{\text{g}} = 10,000 \frac{\text{mg}}{\text{L}}$$

To achieve a desired concentration of 20 ppb, 100 μl of the above solution was injected into a tank containing 50 liters of water. The water and chemicals were gently mechanically mixed with a wooden rod.

$$100\mu L \times \frac{\frac{1}{10^6\mu L} \times 10,000 \frac{mg}{L} \times \frac{10^3\mu g}{mg}}{50L} = \frac{20\mu g}{L}$$



Figure 4.2 Model Monitoring Well Set-Up

When the filling of the tank with water was completed, a Teflon bailer, which had been cleaned and stored in aluminum foil, was lowered down the monitoring well to obtain a water sample. This first bailer sample was discarded. The bailer

was again lowered down the well to obtain a sample. Upon retrieval, two 40 mL glass vials (teflon sealed) were filled using the bottom control flow valve. While inserting the flow control valve into the bottom of the bailer, it appeared that a small air bubble was introduced into the water and traveled up through the bailer. Two 40 mL glass vials were also filled by decanting the water through the top of the bailer. The vials were refrigerated for sample preservation. A BAT probe (Figure 4.3) was then lowered down through the center of the well to obtain samples. The first sample was discarded because 8 mL of the water in the sample was from the water that was used to saturate the porous filter. Three attempts were made to obtain samples using the cascaded type system of two test tubes in series (Figure 4.4). This procedure was used to collect a bottom tube sample with no headspace while the upper sample will contain some headspace. Cascaded BAT samples were numbered with odd integers for the lower (zero headspace) tube samples, e.g BAT3, and with the next (even) integer for the upper (with headspace) tube sample for the same test. Only one of the three attempts yielded a sample with no headspace. There appeared to be a bad connection between the two test tubes. In the two unsuccessful attempts, the bottom test tubes were partially filled while the upper tubes were empty. The upper test tubes when opened still had vacuums. Samples were stored for less than one day before performing the chemical analyses. Results are shown in Table

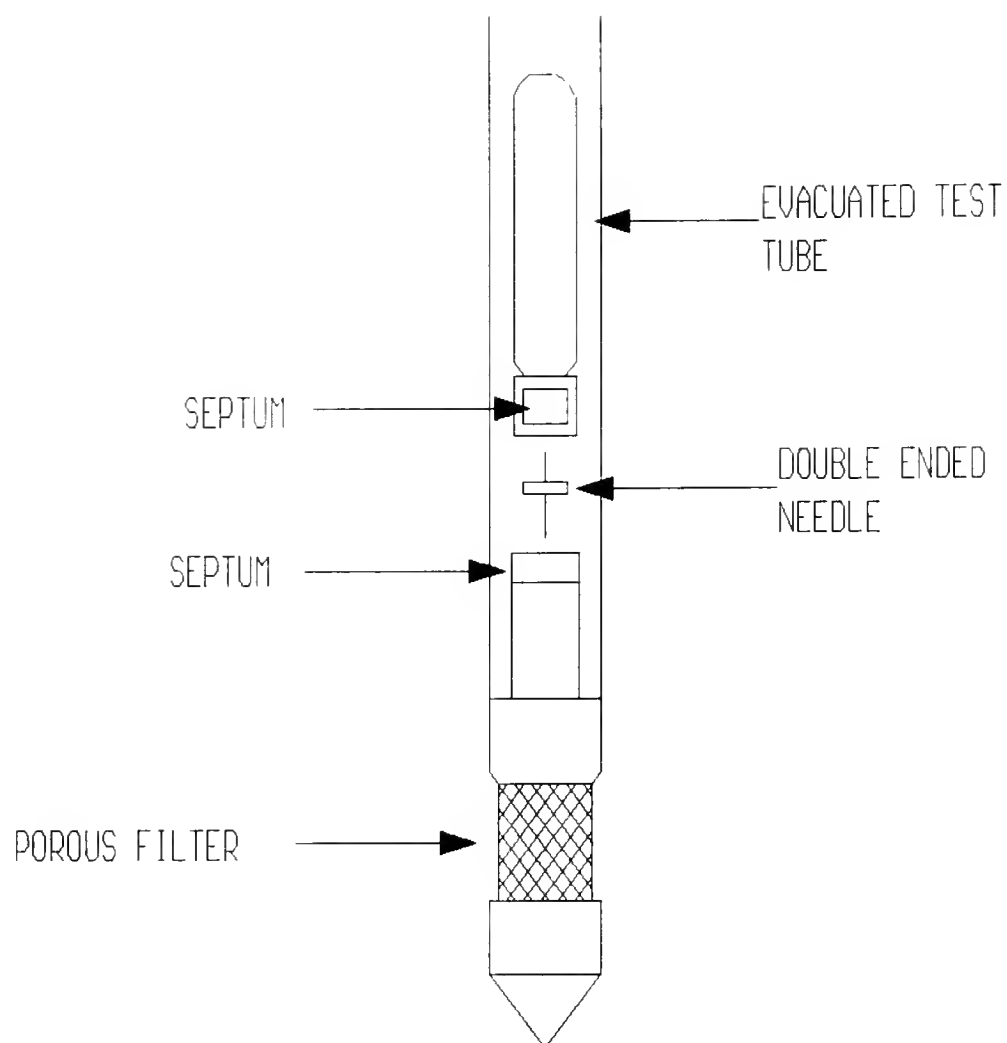


Figure 4.3 BAT MK2 Probe

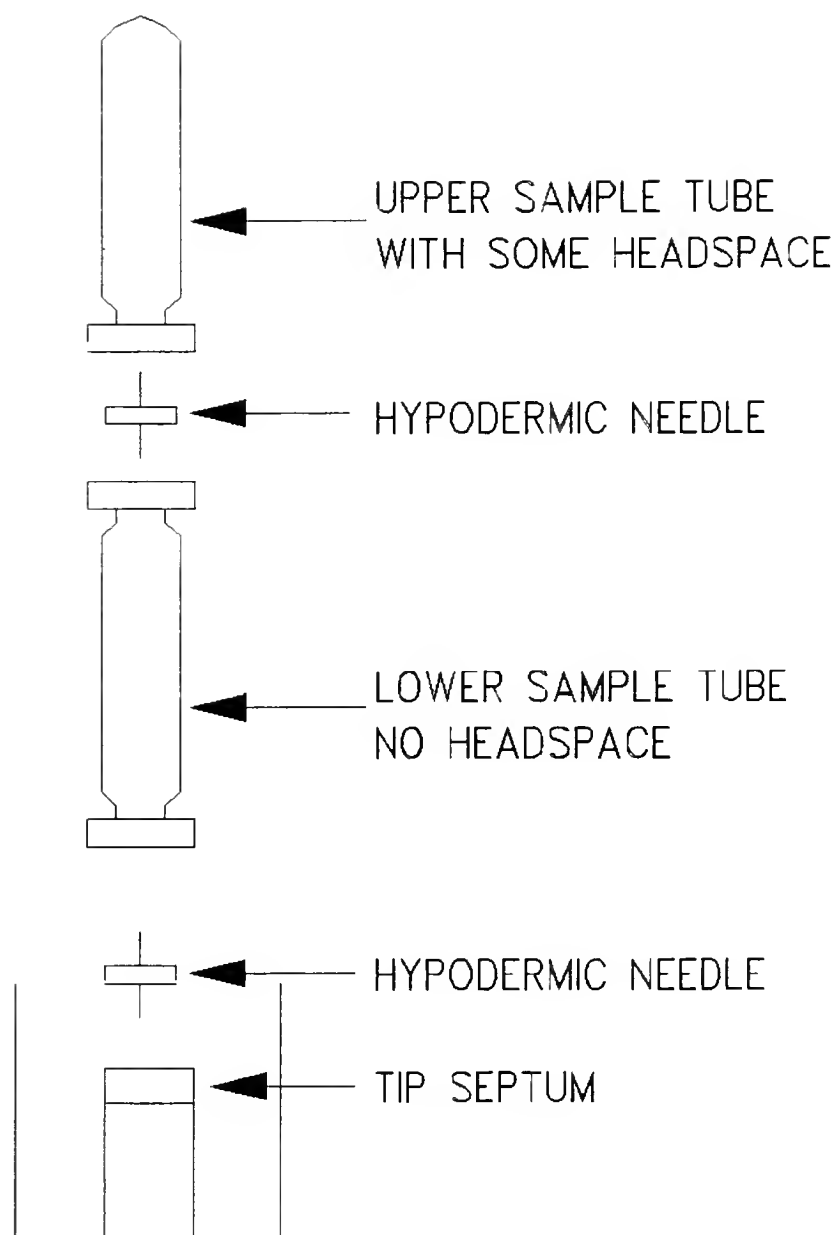


Figure 4.4 Cascaded Sampling for Zero Head Space Sample

4.1. The bailer samples recovered more VOCs than did the BAT samples. The single BAT sample with no headspace still recovered 3% less benzene, 15% less toluene, and 24% less xylene than did the average of all the bailer samples.

4.4 Experiment 2 Inside the Model Monitoring Well

After the chemicals had remained in the drum for three days, additional samples were taken. Two full samples without headspace were obtained using the cascaded technique (BAT1 and BAT3) and one sample was obtained using the single vial technique (BAT5). These samples were also taken by placing the BAT probe down the center of the monitoring well. The results are shown in Table 4.2.

These two rounds of sampling did show the effect that headspace has on the loss of VOCs. Generally, the larger the headspace the smaller the amount of VOCs observed. The sample that was obtained during experiment 1 which was stored for five days did not show any additional loss of VOCs as compared to those stored for only one day.

A very important factor discovered was that the method of extracting the water sample from the BAT test tubes played a large role in the levels of observed contaminants. It was determined that the best method to obtain the water from a double-ended test tube was to hold the tube vertically, remove the top end of the test tube, insert the needle of the syringe through the bottom end and draw the water out of the test

Table 4.1 Chemical Analyses of Sampling Within Model Monitoring Well

SAMPLE	HEAD SPACE %	BENZENE ppb	TOLUENE ppb	XYLENE ppb	COMMENTS
TANK WATER		14.6	11.8	12.1	
BAT	15	13.7	8.8	7.8	SINGLE- ENDED TEST TUBE
BAILER		16.1	11.2	12.3	BOTTOM FLOW CONTROL VALVE
BAT	57	10.3	8.0	7.3	DOUBLE- ENDED TEST TUBE
BAILER TOP		16.0	11.8	12.4	DECANTED
BAILER TOP		16.8	12.2	12.9	DECANTED
BAT	0	16.0	10.0	9.6	DOUBLE- ENDED TEST TUBE
BAT	50	11.9	6.7	6.4	DECANTED THROUGH NECK
BAILER		17.0	12.0	13.0	BOTTOM FLOW CONTROL VALVE
AVG BAILER		16.5	11.8	12.7	

True concentration of water in tank was to be 20 ppb (20 $\mu\text{g/l}$).
 BAT samples obtained by lowering probe down the center of the pvc monitoring well.

Table 4.2 Chemical Analyses of Experiment Two Inside the Model Monitoring Well

SAMPLE	HEAD SPACE %	BENZENE ppb	TOLUENE ppb	XYLENE ppb	COMMENTS
BAT1	0	4.7	2.7	4.7	DOUBLE-ENDED TEST TUBE NEEDLE EXTRACTED
BAT2	9	3.5	2.7	4.4	SINGLE-ENDED TEST TUBE NEEDLE EXTRACTED
BAT3	0	2.6	1.5	3.7	DOUBLE-ENDED TEST TUBE NEEDLE EXTRACTED
BAT4	43	2.8	1.8	3.8	SINGLE-ENDED TEST TUBE NEEDLE EXTRACTED
BAT5	5	2.3	1.3	2.9	SINGLE-ENDED TEST TUBE NEEDLE EXTRACTED
BAT STORED FIVE DAYS (FROM EXPERIMENT 1)	39	11.8	7.2	5.0	DOUBLE-ENDED TEST TUBE NEEDLE EXTRACTED

tube. When extracting the sample with both ends sealed (also occurs when using a sealed single-ended test tube), it becomes quite difficult to remove the sample and if the

analyst is not careful the sample can be pulled back into the test tube. If an additional needle is placed in the bottom test tube to relieve the vacuum while the sample is being extracted with the syringe, little air bubbles move up through the sample. This may cause a loss of VOCs. Water should be slowly drawn out of the test tubes to allow the syringe to gradually fill without any headspace. If the water is removed too quickly, bubbling can occur as the water enters the syringe. The most successful method for extracting the water from a single-ended test tube is to remove the end of the test tube and to hold the test tube in a near horizontal position. The needle of the syringe is then placed in the test tube and kept under the water level. As the water level is lowered, the test tube is inverted slightly to keep the needle under the water. Another method not attempted would be to remove the seal and, holding the tube vertically, use a syringe with a long enough needle to reach the bottom of the test tube. If an adequate needle is not available, it may be possible to place a length of thin tubing over the needle which can be lowered down the test tube.

4.5 Experiment 3 Inside the Model Monitoring Well

A third round of testing was performed after draining the water from the tank the previous day. A new contaminated solution of 20 ppb each of benzene, toluene, and o-xylene was mixed and slowly siphoned by gravity down the monitoring well

to fill the model. A 40 mL vial was filled with the contaminated water. A Teflon bailer was used to obtain two samples from the well (BAILER1 and BAILER2). This sampling was performed within 5 minutes of the filling. Since there was little time for interaction between the contaminants and the pvc well, no purging was performed.

BAT probe sampling was performed for the first time in the soil, adjacent to the monitoring well. The probe was pushed to the bottom of the tank using a hydraulic jack. A load frame constructed of four inch steel channel, and shown in Figure 4.5, provided the reaction for the penetration push. Two samples without headspace (BAT1 and BAT3) were obtained after drawing the water out of the filter. The BAT probe was then removed from the tank and a second probe inserted at a different location and to a shallower depth. Two samples with no headspace (BAT5 and BAT7) were obtained from this depth. The results of the chemical analyses are shown in Table 4.3. The bailer samples contained higher concentrations of contaminants than the BAT samples. The BAT samples taken from the very bottom of the tank were quite low. This was probably due to incomplete draining of the tank which allowed the old contaminated water to be sampled. The longer the water remains in the tank, the greater the chance of sorption of the contaminants onto the soil and loss of VOCs. The concentrations of contaminants in the upper BAT samples were closer to those obtained from the bailer samples, but were



Figure 4.5 BAT Probe with Reaction Frame

still generally around 35% lower.

At this time, it was believed that there were two principal reasons why the BAT system was not recovering similar levels of VOCs as the bailer. One reason was that the bailer samples were taken within a few minutes of filling the well, with little time for the VOCs to volatilize. The water obtained from the BAT samples taken a couple of hours later,

Table 4.3 Chemical Analyses of BAT Probe Sampling Inside the Model Monitoring Well

SAMPLE	HEAD SPACE %	BENZENE ppb	TOLUENE ppb	XYLENE ppb	COMMENTS
TANK WATER		18.1	21.3	24.3	
BAILER		17.7	19.0	21.5	
BAILER		15.5	16.4	18.6	
BAT1	0	4.4	3.4	2.1	BOTTOM OF TANK
BAT3	0	5.2	4.2	2.7	BOTTOM OF TANK
BAT5	0	10.6	10.6	9.4	UPPER PART OF TANK
BAT7	0	12.4	12.0	13.9	UPPER PART OF TANK
BAT pushed into the soil with the use of Hydraulic Jack.					
Water spiked to provide concentrations of 20 µg/l (ppb) for each contaminant.					

however, had plenty of time to interact (sorb) with the soil perhaps resulting in a lower recovery of VOCs. The second possible explanation for the lower recovery of VOCs was that the BAT's use of a vacuum causes a loss of VOCs. It was thought that the water entering the BAT test tube would bubble due to the vacuum which had been placed on the test tube. The bubbling would cause a loss of volatiles as they would enter

the gaseous phase. A lab experiment was performed to see if the water did bubble when entering the test tube. A vacuum was placed on two test tubes which were then connected with a double-ended needle. Another double-ended needle was placed into the septum of the BAT probe, which had been placed in a bucket of water. The bottom test tube was then placed in contact with the exposed needle from the BAT probe. At the instant contact was made, water was pulled into the test tube and bubbling did occur. Bubbling occurred but it became less dramatic as the test tube filled.

The test was repeated with the probe's porous filter removed to see if it could have been only partially saturated. In which case, the bubbles that formed would be due to air entrapped in the porous filter and pulled into the test tube. The test showed considerable bubbling, which eliminated the filter as the responsible party.

Another test was performed using degassed water (boiled water) to see if the bubbling effect was due to dissolved gas being pulled out of solution by the vacuum. Less bubbling occurred. Bubbling will probably always occur as long as there is a head space when the water enters the test tube. When a syringe without any headspace is used to slowly withdraw water from a test tube or vial almost no bubbling occurs. If the syringe is pulled strongly back and a headspace is formed, the water will bubble when entering the syringe due to the reduced pressure.

In order to eliminate headspace it was decided to make use of a membrane inside a double-ended test tube. A balloon was used as the membrane. The balloon was placed in the test tube with its opening stretched over the neck of the test tube. The top was then screwed on over the balloon (Figure 4.6). A syringe was inserted through this top to evacuate the air from the balloon. This caused the balloon to collapse. The top was then screwed onto the other end of the test tube and the air evacuated with a syringe. This membrane test tube was used with the probe in the lab with tap water with virtually a 100% success rate. When sampling, the water would enter the balloon and fill it. Once the unstretched length of the balloon filled, it would continue to fill as the water stretched the balloon until it came in contact with the walls of the glass tube. The water would then continue to expand the balloon upward. When viewing the test tube after sampling, a small bubble was observed in the water filled balloon.

4.6 Experiment 4--Sampling Within Tank Spiked Water

This experiment consisted of filling a nalgene container with 200 liters of distilled water. The container had less than 10% headspace. Benzene, toluene, and o-xylene were injected into the tank to give it a concentration of 10 $\mu\text{g/l}$ of each contaminant. The tank was mechanically mixed with a pvc slotted well screen. The objective here was to directly

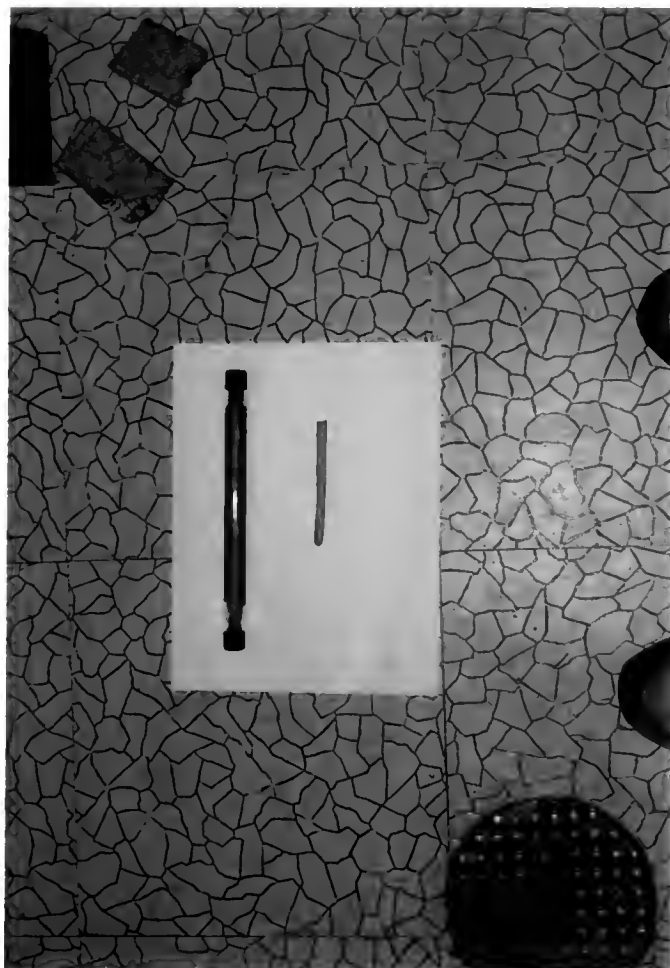


Figure 4.6 Balloon and Test Tube Apparatus

compare the bailer and the BAT without the presence of the sand. The sand was thought to sorb some of the contaminants, resulting in the lower recovery of volatiles by the BAT system in earlier experiments.

The BAT probe was lowered into the tank and suspended slightly below the water level using two "C" clamps on the drill rod, Figure 4.7. Tape was placed around the drill rod to seal the hole and the escape of any gaseous fumes. The



Figure 4.7 BAT Sampling in Nalgene Container

first BAT sample was as usual discarded, as it contained at least 8 mL of the distilled water which had been used to saturate the probe. Three BAT samples (BAT1, BAT3 and BAT5) were collected without headspace by the cascaded technique. A minimum of 10 minutes was required to completely fill the bottom test tube before any filling of the upper test tube occurred. Two BAT samples (BAT7 and BAT8) obtained using a single-ended test tube, filled approximately 90% within 7

minutes. Two BAT samples, BAT9 and BAT10, were obtained using the balloon technique. After sampling with the BAT system, two samples of the tank water were obtained with the Teflon bailer, BAILER1 and BAILER2.

Results of the chemical analyses are shown in Table 4.4. The bailer samples again recovered the highest percentages of VOCs. Samples using the balloon technique recovered the lowest percentage of VOCs. This was undoubtedly due to sorption of the contaminants onto the rubber balloon. There was an extreme variation in the results obtained from the BAT samples with and without headspace.

Statistical data such as the standard deviation (STD) and the relative standard deviation (RSD) were calculated from the equations given below. The relative standard deviation is also known as the coefficient of variation. The standard deviation and relative standard deviation are both measures of skewness. They give us an idea on the precision of our data. The smaller the skewness in the data the higher the precision in the sampling procedure and device. This infers that the sampling procedure is also highly reproducible and gives us a high level of confidence.

Table 4.4 Chemical Analyses of Sampling Within Tank Spiked Water

SAMPLE	HEAD SPACE %	BENZENE ppb	TOLUENE ppb	XYLENE ppb	COMMENTS
BAT9	0	2.49	1.29	0.56	BALLOON
BAT10	0	1.72	1.01	0.44	BALLOON
BAT1	0	5.84	7.01	7.81	PRESSURIZED BEFORE EXTRACTING
BAT3	0	9.02	9.10	9.20	
BAT4	50	5.40	6.30	6.96	
BAT5	0	7.68	8.65	9.13	
BAT7	11	8.20	7.69	8.21	EXCLUDING BALLOON SAMPLES
BAT8	10	8.61	8.30	9.50	
AVG BAT		7.46	7.84	8.47	
BAT-NO HEAD SPACE (#1,3,5)					
AVG		7.51	8.25	8.71	
STD		1.3	0.9	0.6	
RSD		17.3	10.8	6.9	
BAILER1		9.08	9.80	11.20	
BAILER2		9.60	9.99	11.90	
AVG BAILER		9.34	9.90	11.55	
STD		0.3	0.1	0.3	
RSD		3.2	1.0	2.6	

Tank Spiked to give actual concentrations of 10 µg/l (ppb) for each contaminant.

$$STD = \sqrt{\frac{\sum (X - \bar{X})^2}{N}}$$

$$RSD = \frac{STD}{\bar{X}} \times 100$$

X = actual concentration
X̄ = mean concentration
N = number of samples

4.7 Experiment 5--Sampling Within Tank Spiked Water

This experiment consisted of spiking 225 liters of water with benzene, toluene, and xylene to achieve a concentration of 8.9 ppb for each contaminant. The chemicals were mixed mechanically as in Experiment 4. The container had less than 2% headspace. Five samples (BAT1, BAT3... BAT9) without headspace were collected with the BAT probe using the cascaded technique. Each test tube did contain a small bubble. Five samples were obtained with the teflon bailer by decanting from the top into 40 mL vials. Results of the chemical analyses are shown in Table 4.5.

Since the results again showed that the BAT recovered lower BTX concentrations, an attempt was made to obtain samples using hydrostatic pressure rather than with reduced pressure. This method is used by the Hydropunch system. A cascaded type system was used with two modifications. Two double-ended test tubes were used. A cap was not placed on the top of the upper test tube. This allowed air to vent from the test tubes as they filled. The second modification consisted of drilling a hole into the top of the metal plug

which is screwed down on to the test tube container housing. This allowed the air to vent from the test tube and from the container housing.

The BAT probe was placed approximately three feet below the container free water surface. After sixteen hours the lower test tube was about 80% (28 mL) full. Such a length of time would, in most situations be impractical. Also such a long period of time would allow a significant amount of the VOCs to vaporize.

Another attempt at collecting a sample hydrostatically was performed. The threaded glass ends were removed from the tube and fused onto a smaller diameter tube of approximately the same length. The modified tube held approximately 12.5 mL of water, about 1/3 the standard tube's volume. It was hoped this would significantly reduce the time required for sampling. The modified tube filled completely, with no headspace, and approximately 10 mL entered the upper tube within seventeen hours. This however was also considered inadequate.

4.8 Experiment 6--Sampling Within Tank Spiked Water

This experiment again used the balloon technique. Testing was as previously tried with the exception that the

Table 4.5 Chemical Analyses from Sampling Within Tank Spiked Water

SAMPLE	HEAD SPACE	BENZENE ppb	TOLUENE ppb	XYLENE ppb
BAILER1	0	9.9	9.7	10.1
BAILER2	0	9.5	9.1	10.0
BAILER3	0	7.4	9.7	10.7
BAILER4	0	9.9	9.9	10.6
BAILER5	0	8.3	10.2	11.0
AVG BAILER		9.0	9.7	10.5
STANDARD DEVIATION		1.0	0.4	0.4
RELATIVE STANDARD DEVIATION		11.1	4.1	3.8
BAT1	0	6.9	9.1	9.1
BAT3	0	7.6	9.1	9.4
BAT5	0	8.4	8.7	8.7
BAT7	0	6.7	9.0	9.3
BAT9	0	6.7	8.4	8.4
AVG BAT		7.3	8.9	9.0
STANDARD DEVIATION		0.7	0.3	0.4
RELATIVE STANDARD DEVIATION		9.6	3.4	4.4
BAT % LOWER		18.9	8.2	14.3

Tank spiked to provide actual concentrations of 10 µg/l (10 ppb) for each of the contaminants.

inside of the balloon was sprayed with a dry film lubricant and mold release agent, manufactured by Crown Industrial Products of Hebron, Illinois (#6075). The product label states that it is chemically similar to TFE (Teflon) as manufactured by Dupont.

A solution of 10 ppb (10 $\mu\text{g/l}$) of benzene, toluene, and xylene was made. Three BAT samples (BAT1, BAT3 and BAT5) with no headspace were taken using the cascade technique. Two BAT samples were collected using the balloon which had been coated with the teflon spray. Two bailer samples (BAILER1 and BAILER2) were obtained for comparison. The results are shown in Table 4.6.

After performing the chemical analysis on the two bailer samples and two of the no headspace BAT samples, analysis was performed on the balloon sample. This sample overloaded the GC/MS system due to the freon propellant that is used in the teflon spray coating. The third BAT sample with no head space was run directly after the balloon sample but could not be properly interpreted. Analysis on the second balloon sample was not performed. In this test the BAT samples, without any headspace recovered more VOCs than did the Teflon bailer.

4.9 Teflon Ball and Tube Sampling Apparatus

Another modification to the BAT system was tried to obtain zero headspace samples. Teflon tubes were manufactured

with a constant inner diameter of 1/4 inch and threads machined on either end to fit the BAT test tube caps.

A Teflon ball, 1/4 inch in diameter, was placed inside the Teflon tube. The ball was to be in contact with the walls of the tube with no air space around the wall. After the ball was placed in the end of the tube, one cap was screwed on and a vacuum pulled on that side of the tube. The second cap was then screwed onto the other end and a vacuum placed on that side. When the hypodermic needle made contact with the BAT septum and the septum of the Teflon tube, it was hoped that the higher pressure of the water would push the teflon ball up the tube and yield a sample without any head space.

Table 4.6 Chemical Analyses of Experiment 6

SAMPLE	HEAD SPACE	BENZENE ppb	TOLUENE ppb	XYLENE ppb
BAILER1	0	11.4	10.0	8.9
BAILER2	0	10.7	8.8	8.2
AVG BAILER		11.1	9.4	8.6
BAT1	0	12.0	10.3	9.5
BAT7	0	11.9	10.0	8.4
AVG BAT	0	12.0	10.2	9.0
BAILER % LOWER THAN BAT		7.5	7.8	4.4
Water spiked to provide actual concentration levels of 10 μg/l (10 ppb) for each contaminant.				

Several trials with this method met little success. Even though Teflon has a very low coefficient of friction, the water pressure was not sufficient to push the ball up the tube. The diameter of the tube was slightly enlarged to see if this would help. The ball did move slightly better, but would typically become stuck somewhere in the middle of the tube. This was probably due to the flexibility of the teflon tube. If the tube became the slightest bit distorted in any direction, the inner diameter would change and cause the ball to become stuck.

4.10 BAT Vadose Zone Probe Testing

Laboratory testing was conducted with a BAT probe using a ceramic filter. Such a filter, with its small pore size of 2 microns, is necessary if sampling is to be attempted in the unsaturated zone. Standard BAT filters made of steel or HDPE have larger pore sizes. These filters allow air to be pulled into the filter which inhibits the flow of water because a full vacuum cannot be maintained. This means sampling is greatly hindered.

A uniform fine silica sand was placed in a plastic concrete cylinder casing (12" high by 6" diameter) to a height of 8 inches. Before placing the sand in the container a small hole was made in the bottom of the casing to allow water to drain out. A piece of white cotton sheet was taped over the hole on the inside of the casing to serve as a filter. A

piece of strapping tape was placed over the hole on the outside of the casing to inhibit flow.

The dry soil had a mass of 6012 grams. Water, with a mass of 1555 grams was then poured into the soil. The strapping tape was removed and the water allowed to drain into a pan. When drainage was complete, 161 grams of water had been collected, which left 1394 grams in the soil. The initial water content (by weight) was then 23.2% and the moist unit weight was 124.5 pcf. The BAT probe with ceramic filter was then saturated in a bucket of water and pushed by hand into the soil filled cylinder. Pore pressure readings were taken and sampling performed with the BAT groundwater monitoring system. Results are shown in Table 4.7.

Some problems were evident with the pore pressure readings. By removing the water from the soil the pressure should have become more negative as the test progressed. The pore pressure reading problems could have been caused from all the water in the ceramic filter being pulled out.

By taking a soil sample from the field and performing a test like that above, the soil moisture curve could be developed. A typical soil moisture curve is shown in Figure 4.8. With this information pore pressures could be read in the field and correlated to the actual water content from this graph. The soil water content profile is needed for all unsaturated flow problems.

4.11 Summary

Testing within a tank filled with water spiked with gasoline constituents proved to be a better method than modeling a well inside a 55-gallon drum filled with sand. For the two experiments in the tank filled water there was conflicting data. In one test the bailer recovered more VOCs than did the BAT probe and in the other test the BAT probe recovered more than the bailer. The data from the BAT probe showed it to be a more precise device than the bailer by having a lower relative standard deviation.

Table 4.7 Vadose Probe Testing

Sampling Time	Water Recovered mL (Water content)	Pore Pressure cm of Water
20 min	4 (23.1%)	-.42
40 min	1.5 (23.1%)	-.43
2 hrs 15 min	4 (23.0%)	-.42
24 hrs 15 min	23.5 (22.6%)	0.0
43 hrs 30 min	0.0	-.03

Evaporation was not considered in water calculations.

Water = 1 g/cm³

1 ml = 1 cm³

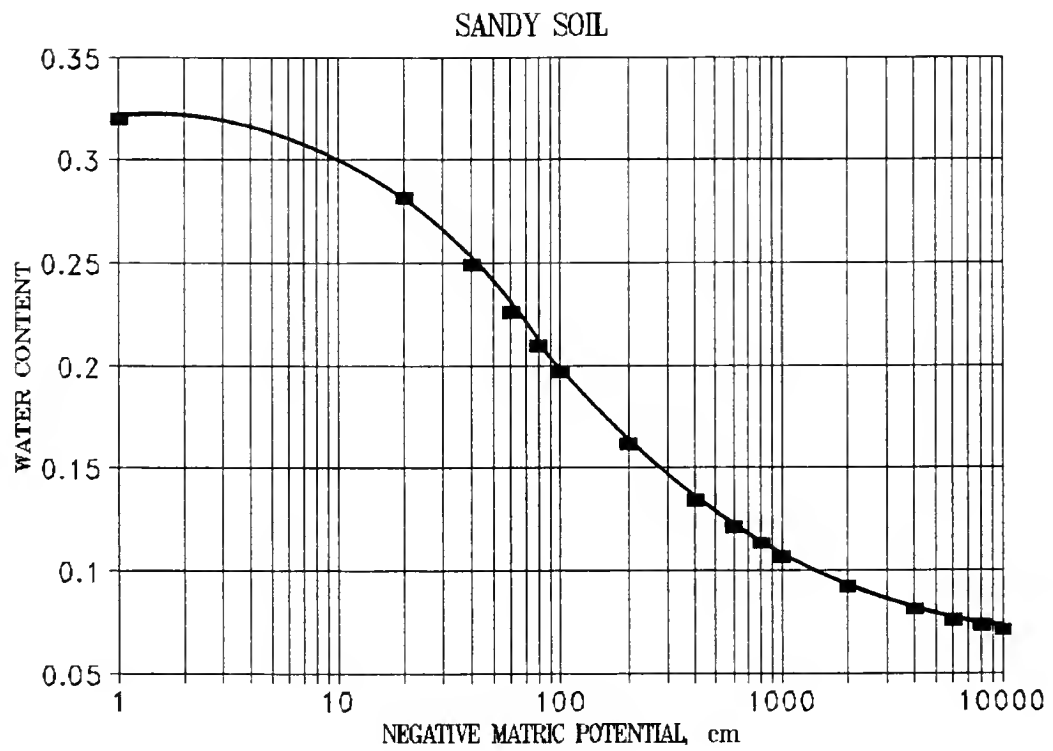


Figure 4.8 Typical Soil Moisture Curve

CHAPTER 5 ANALYSIS, TRANSPORT, AND PROPERTIES OF VOLATILE ORGANIC COMPOUNDS

5.1 Introduction

This chapter is provided to give a overview of some basic principles of geo-environmental engineering. Discussions are provided on organic compounds, chemical analysis of water samples, regulatory contaminant levels, and solute transport. This background information is necessary before looking at the field contaminant studies that were performed.

5.2 Organic Compounds

Organic compounds are defined as compounds which contain some amount of carbon. Hydrocarbons are compounds which contain only hydrogen and carbon. The most familiar hydrocarbons are benzene, toluene, ethylbenzene, and the xylenes. These four compounds are typically known as BTEX. All four are constituents in petroleum products such as gasoline. Petroleum hydrocarbons typically have specific gravities less than one making them float on top of the groundwater in a separate phase. These compounds are sometimes called LNAPLs (Light non aqueous phase liquids) or floaters. Hydrocarbons such as BTEX which typically have low solubilities in water and volatilize easily are known as VOCs. Figure 5.1 illustrates the typical transport of a LNAPL.

Henry's Constant, H , is a coefficient which describes a compound's partitioning between the liquid and vapor phases. The higher the Henry's Constant the more likely the compound is to come out of water and go into a vapor phase. Table 5.1 lists the Henry's Constant of several compounds, from Pankow (1986).

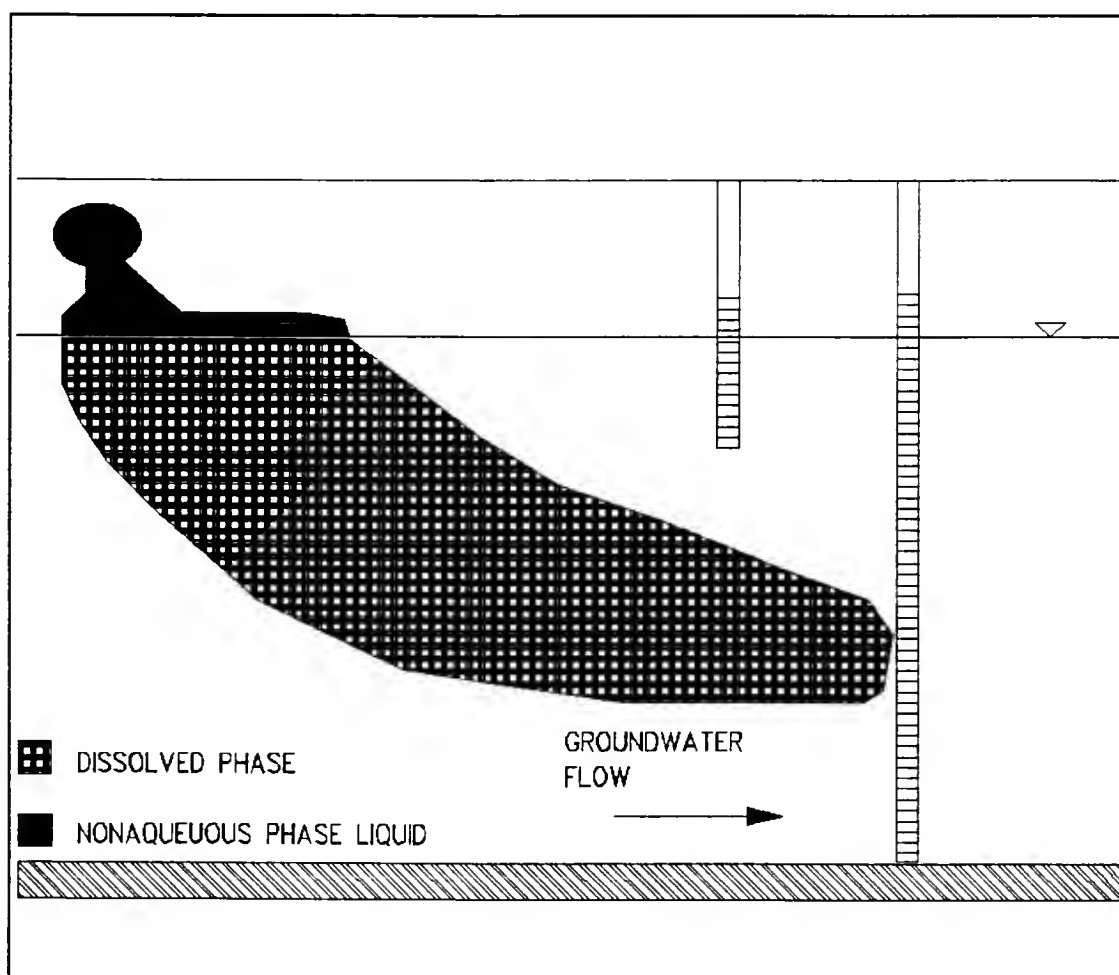


Figure 5.1 Transport of a Typical LNAPL

Table 5.1 Henry's Constant for Selected VOCs

<u>COMPOUND</u>	<u>H</u>	<u>COMPOUND</u>	<u>H</u>
BENZENE	0.0055	METHYLENE CHLORIDE	0.0020
CHLOROBENZENE	0.0036	CHLOROFORM	0.0029
TOLUENE	0.0067	CHLOROETHANE	0.15
ETHYLBENZENE	0.0066	VINYL CHLORIDE	0.081
O-XYLENE	0.0050	TRICHLOROETHENE	0.0091
M-XYLENE	0.0070	TETRACHLOROETHENE	0.0153
P-XYLENE	0.0071	ETHYLENE DIBROMIDE	0.00082

H is in atm·m³/mol

If VOCs are present in groundwater they vaporize and migrate vertically and horizontally in the gas phase through the soil pores until they reach the atmosphere. This is a natural remediation process. Ballestro et al. (1991) state that nonhalogenated compounds such as BTEX, when present in low concentrations in groundwater, readily degrade in oxygenated soil. This does not occur, however, when large concentrations are present.

Halogenated organic compounds contain hydrogen, carbon, and one or more of the halogens, fluorine, chlorine, bromine, or iodine.

Chlorinated compounds are typically denser than water and are known as sinkers or dense non-aqueous phase liquids

(DNAPLs). These compounds will sink through groundwater until they reach a confining layer and will then move laterally with gravity. If the confining layer is angled, the contaminant can even move upgradient. Figure 5.2 illustrates a simulated transport of a DNAPL. Chlorinated DNAPLs include chloroform, tetrachloroethene or perchloroethene (PCE), trichloroethene (TCE), methylene chloride, 1,1,1-trichloroethane (TCA) and, 1,1,2-trichlorotrifluoroethane (freon). Trichloroethene is a degreasing solvent and is the most common contaminant found in groundwater. Tetrachloroethene is used in dry cleaning fluid.

5.3 Chemical Analysis

Once groundwater samples are taken they must be analyzed to determine the presence and concentration of contaminants. For gasoline spills or leaking underground storage tanks, EPA Method 602 titled Purgeable Aromatics is run to determine the presence and concentration of the aromatic chemicals. These include benzene, chlorobenzene, the three dichlorobenzenes, ethylbenzene, and toluene. This analysis consists of injecting a sample into a purging device where an inert gas such as helium is bubbled through the water sample to volatilize the contaminants. These are then trapped on a sorbant material. The trap is then heated and backflushed with helium to desorb the contaminants which are then sent to a gas chromatograph (GC) for separation and detection. Before

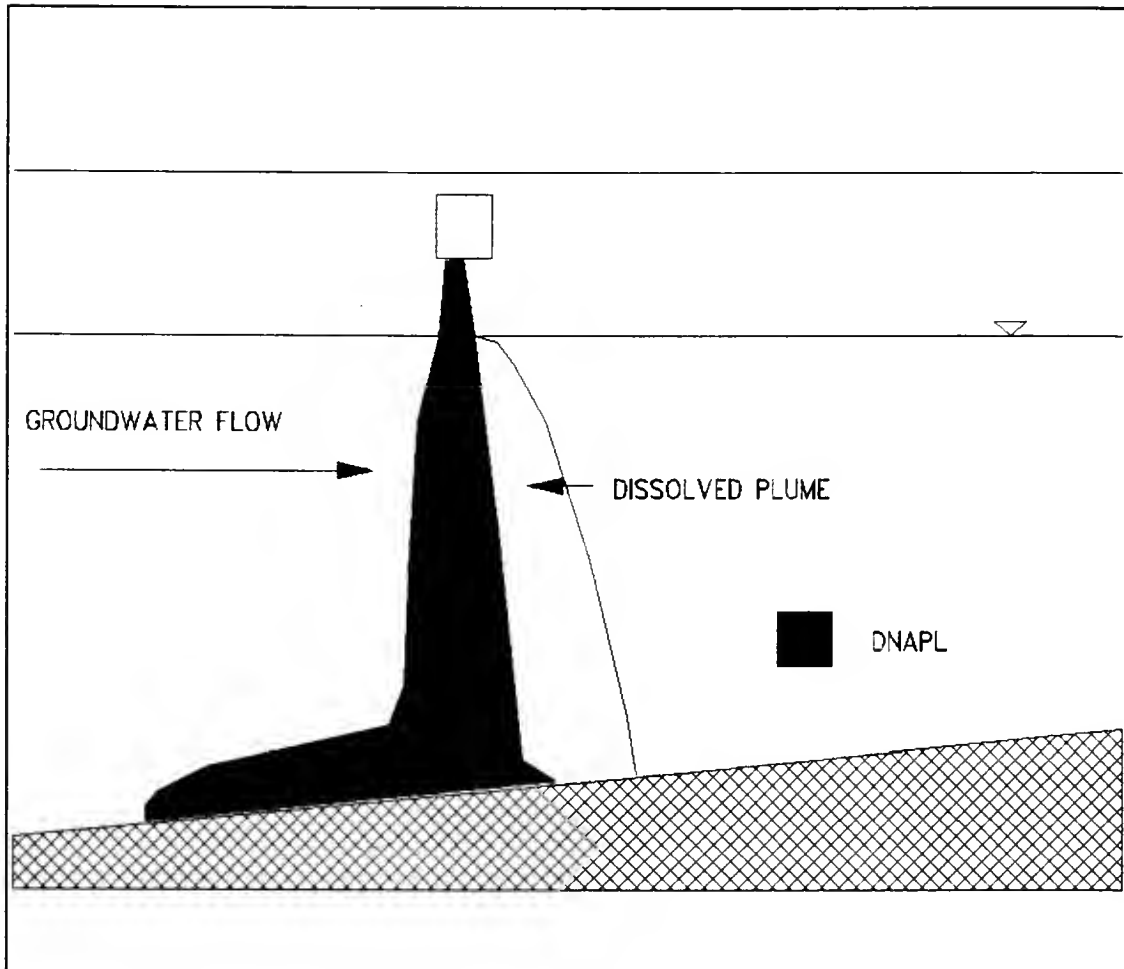


Figure 5.2 Transport of DNAPL

running any samples the gas chromatograph must be calibrated for the contaminants of concern.

These contaminants are individually run through the gas chromatograph since it cannot absolutely distinguish between compounds. By running each compound separately the retention time is determined for each compound. Compounds come off the GC column in order of their boiling points. With this method there can still be some error because several compounds may

elute (come off the column) at the same retention time. Figure 5.3 shows a typical total ion chromatograph.

The state of the art for groundwater analysis makes use of a gas chromatograph in conjunction with a mass spectrometer (GC/MS). EPA Method 624 titled Purgeables makes use of the GC/MS for the detection and quantitation of not only the seven contaminants found in Method 602 but 24 other compounds. This analysis is run in a similar manner to that of Method 602 with the exception that after the sample leaves the GC it is sent to the mass spectrometer. The mass spectrometer bombards the compounds with electrons to try to ionize them by knocking off electrons and some of the atoms. As the compound is bombarded with electrons it is scanned several times a second to determine the atomic mass units (AMUs) that are present and their relative intensities. This allows better determination of compounds. Each compound has a mass spectrum which is its own unique fingerprint under the given conditions. The mass spectrum of a compound shows the fragmentation ions that are present and their relative amounts. A typical mass spectrum is shown in Figure 5.4. The compound shown is o-xylene (1,2 dimethylbenzene). Its chemical formula is C_8H_{10} resulting in a molecular weight of 106. This is one of the peaks shown. Another peak shown is 91 which comes when a methyl group (CH_3), having a weight of 15, is knocked off the compound. The mass spectrum for each peak can be viewed to determine

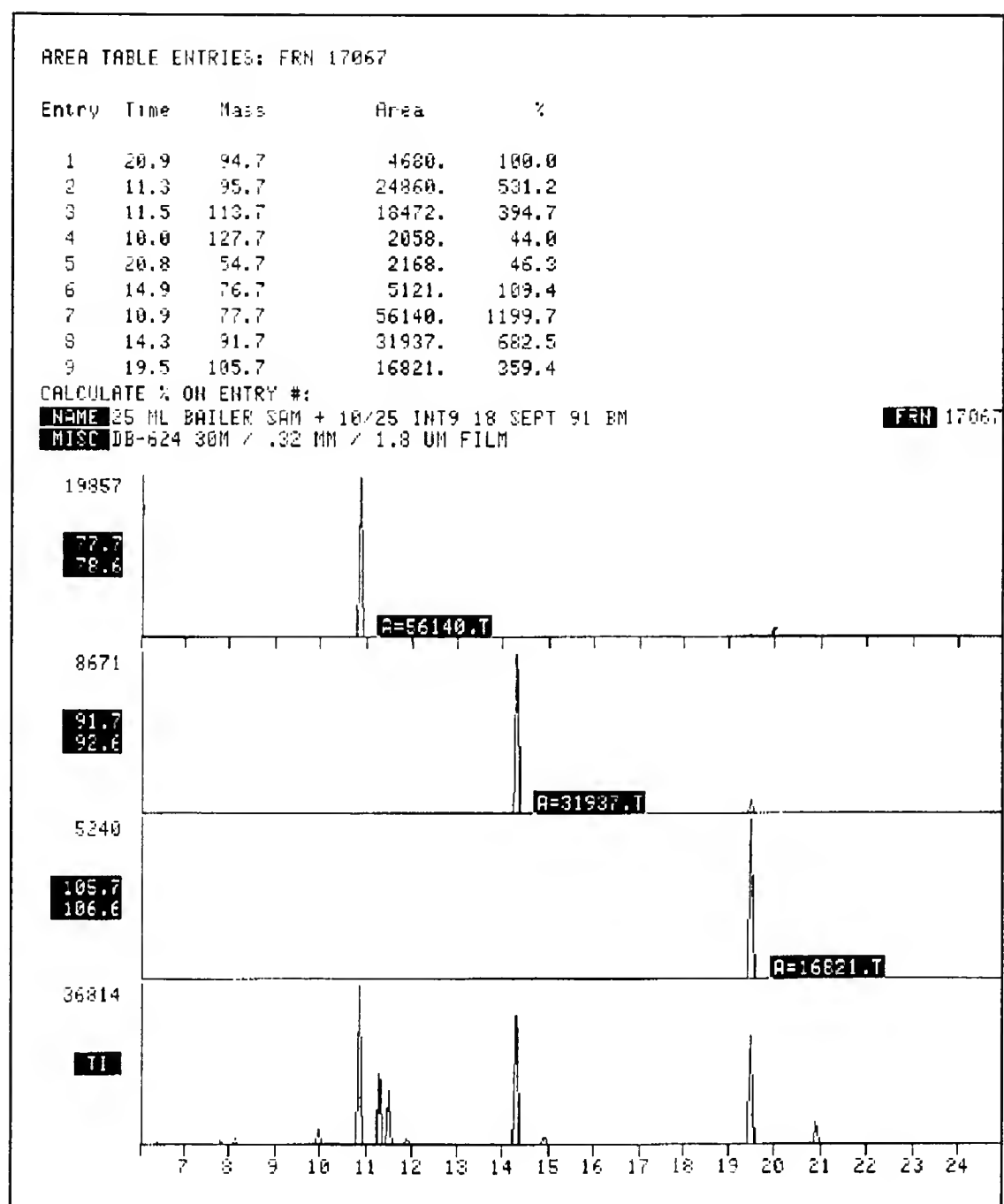


Figure 5.3 Typical Ion Chromatograph

what compound or compounds are present at that particular retention time.

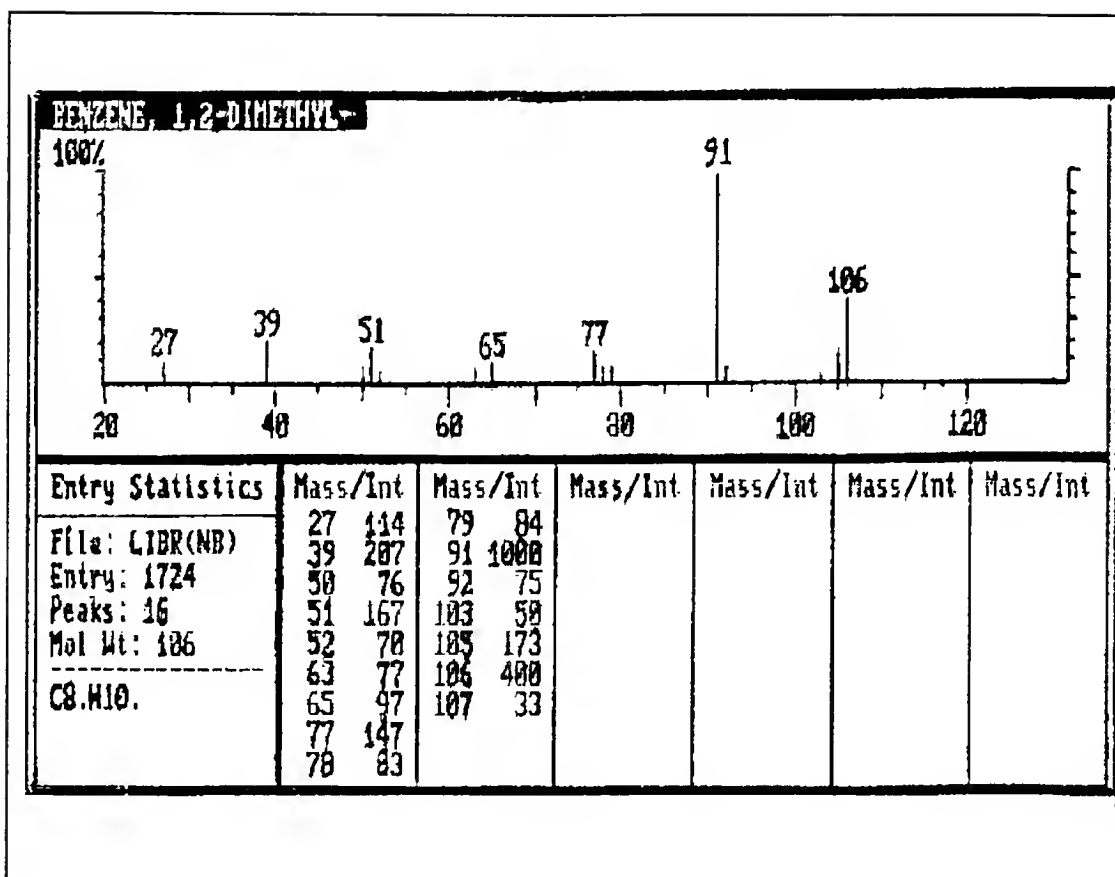


Figure 5.4 Typical Mass Spectra

Before running any samples the GC/MS must be calibrated. This is done by running known compounds at known concentrations through the system to obtain response factors. Response factors are the actual known concentrations divided by the peak area for the compound in question. These factors are obtained by running a wide range of concentrations of the particular compounds such as 2 ppb, 4ppb, 10 ppb, and 20 ppb. These data are then averaged to give a response factor for each compound to be analyzed.

Table 5.2 Primary Drinking Water Standards (MCLs)

Metals	$\mu\text{g/l}$
Arsenic	50
Barium	1000
Cadmium	10
Chromium	50
Lead	50
Mercury	2
Selenium	10
Volatile Organics	
Vinyl Chloride	2
Trichloroethene	5
Benzene	5
Carbon Tetrachloride	5
1,2-Dichloroethene	5
1,1-Dichloroethene	7
1,1,1-Trichloroethane	200
Semivolatiles	
1,4-Dichlorobenzene	75
2,4,5-Trichlorophenol	10
Pesticides/Herbicides	
2,4-Dichlorophenoxyacetic acid	100
gamma-BHC	4
Methoxychlor	100
Toxaphene	5
Additional Parameters	
Nitrate	10,000
Fluoride	4,000

Method 524 titled Measurement of Purgeable Organic Compounds in Water by Capillary Column Gas Chromatography/Mass Spectrometry covers a total of sixty compounds. The method of

detection limit (MDL) depending upon the type of column ranges from .02 to .35 ppb. The method of detection limit is the minimum concentration above zero that is detected 99% of the time.

5.4 Regulatory Contaminant Levels

The Safe Drinking Water Act (SDWA) which was passed in 1974 sets the maximum contaminant levels (MCLs) for drinking water. These levels are listed in Table 5.2. States may, however, implement even more stringent requirements. The Florida Department of Environmental Regulation (DER) has set its own state ground water target levels. For closing an underground storage facility in Florida the contaminant levels must not exceed those listed in Table 5.3. Methyl tert-butyl ether (MTBE) and ethylene dibromide (EDB) are fuel additives. Ethylene dibromide is also used in soil fumigants. Neither of these two compounds is listed in EPA Method 602.

EPA Method 610 is titled Polynuclear Aromatic Hydrocarbons. This method covers sixteen organic compounds that are associated with fuels other than gasoline such as diesel, kerosene, jet fuel A, JP-4 (jet fuel), and No. 6 heating oil. This method requires a minimum sample size of 250 ml. EPA Method 625 titled Base/Neutrals and Acids covers 61 compounds. It includes all the compounds from method 610 plus several polychlorinated biphenyls (PCBs) and several pesticides including DDT, aldrin, chlordane, toxaphene, and dieldrin.

Table 5.3 Florida Ground Water Target Levels

	$\mu\text{g/l}$
Gasoline (EPA Method 602)	
Benzene	1
Total VOA	50
-Benzene	
-Toluene	
-Total Xylenes	
-Ethylbenzene	
Methyl Tert-Butyl Ether (MTBE)	50
Kerosene/Diesel (EPA Method 610)	
Polynuclear Aromatic Hydrocarbons (PAHS)	10

5.5 Solute Transport

Solutes (contaminants) migrate through soil due to three processes: advection, diffusion, and dispersion. Advection is contaminant flowing with the groundwater. Diffusion is the process of spreading due to chemical gradients, i.e., moving from a high concentration to a lower concentration. It can take place when there is no flow of groundwater. Dispersion is the spreading out of the contaminant longitudinally and laterally due to velocity effects as it moves through the tortuous paths through the soil pores. Water moves through the center of pores faster than at the edges where it drags on the soil particles.

The solute transport equation can be derived from the continuity equation:

$$\frac{\partial M}{\partial t} = - \frac{\partial J_T}{\partial x}$$

Where J_T = Total solute flux

$$M = \text{total mass} = \theta C + \rho S$$

$$J_T = -\theta D \frac{\partial C}{\partial x} + qC$$

and q = Darcy flux

D = Hydrodynamic Dispersion Coefficient (lumps dispersion and diffusion together)

θ = Porosity (Volumetric Water Content when saturated)

ρ = Bulk Density of the Soil (ML^{-3})

S = Mass Adsorbed Solute/Mass of the Soil

C = Solution Concentration (ML^{-3})

K_d = Partition or Sorption Coefficient (L^3M^{-1})

$$\theta \frac{\partial C}{\partial t} + C \frac{\partial \theta}{\partial t} + \rho \frac{\partial S}{\partial t} + S \frac{\partial \rho}{\partial t} = - \frac{\partial}{\partial x} [-\theta D \frac{\partial C}{\partial x} + qC]$$

Assume: steady q

constant θ (no change in water content)

constant ρ (no change in soil density)

$$\theta \frac{\partial C}{\partial t} + \rho \frac{\partial S}{\partial t} = \theta D \frac{\partial^2 C}{\partial x^2} - q \frac{\partial C}{\partial x}$$

For linear sorption $S=K_dC$

$$\frac{\partial S}{\partial t} = K_d \frac{\partial C}{\partial t}$$

Substituting for S gives:

$$\theta \frac{\partial C}{\partial t} + \rho K_d \frac{\partial C}{\partial t} = \theta D \frac{\partial^2 C}{\partial x^2} - q \frac{\partial C}{\partial x}$$

Dividing through by θ gives:

$$\left(1 + \frac{\rho K_d}{\theta}\right) \frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - \frac{q}{\theta} \frac{\partial C}{\partial x}$$

$R = \text{Retardation factor} = 1 + \frac{\rho K_d}{\theta}$

$V_o = \text{pore water velocity} = \frac{q}{\theta}$

Substitution gives:

$$R \frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - V_o \frac{\partial C}{\partial x}$$

$V_s = \text{velocity of the solute} = \frac{V_o}{R}$

This shows that the contaminant will travel at a velocity, V_s , which is slower than the velocity of water by a factor R , the retardation factor. For any computer model using the solute transport equation it is necessary to first determine the partition coefficient, K_d . This can be determined by taking a soil sample from the field and

performing a laboratory test in which known contaminants at known concentrations are passed through a column of the soil, and measurements made of the concentrations in the effluent, to determine how much was sorbed by the soil.

It is very important to realize the effect of diffusion in this equation. For years landfills were designed just considering advection. Contaminants were assumed to move just with the water. Clay liners were built with a minimum thickness of three feet and with a permeability of less than 10^{-7} cm/sec. The water velocity becomes negligible when the permeability is small ($v=ki$). Eliminating this from the transport equation shows that the contaminants will still move through the clay barrier before the water will and can contaminate the groundwater. Shackelford and Daniel (1991) have found that in fine grained soils diffusion may be the primary transport mechanism in solute transport. Contaminants may show up below clay liners years earlier than predicted from advection alone.

The retardation factor is a function of the sorption between the contaminants and the soil particles. Sorption can be due to ion exchange where higher valence cations replace lower ones. It can also be due to the hydrophobic nature of some contaminants which easily go out of solution. Clays can retard contaminant migration due not only to their lower permeability but also due to their negative charges which allows for ion exchange unlike sand particles which have small

surfaces areas and no charge. Anions, negatively charged ions, such as Cl^- , NO_3^- , SO_4^- , can be repelled from clays and will move with the water. Soils with a high percentage of organics also retard many contaminants such as pesticides.

Acar and Haider (1990) give the partition coefficients for several contaminants in some particular soils. Generally the order of retardation for some contaminants from lowest to highest is as follows: benzene, toluene, ethylbenzene, and o-xylene.

CHAPTER 6
FIELD STUDIES--CAVALIER PRODUCTS BUILDING SITE

6.1 Introduction

Field work with the BAT groundwater monitoring system was performed at the Cavalier Products Building (previously a Shell gasoline station). The site is located at the intersections of SW 4th Avenue and S. Main Street in Gainesville, Florida. Figure 6.1 shows the site plan. The site is under the jurisdiction of the Alachua County Office of Environmental Protection which contracted with the Handex Company to complete a contamination assessment study. The Handex company installed several 2 inch monitoring wells on the site and also downgradient of the site in Lynch Park.

Two types of tests were performed at this site: BAT probe sampling inside existing monitoring wells and BAT probe sampling within the soil adjacent to the monitoring wells. The purpose of the testing was to show that the BAT groundwater monitoring system could recover VOCs. By collecting samples with the BAT probe inside the monitoring well they could be compared directly to samples obtained with the Teflon bailer from the same monitoring well. The BAT MK2

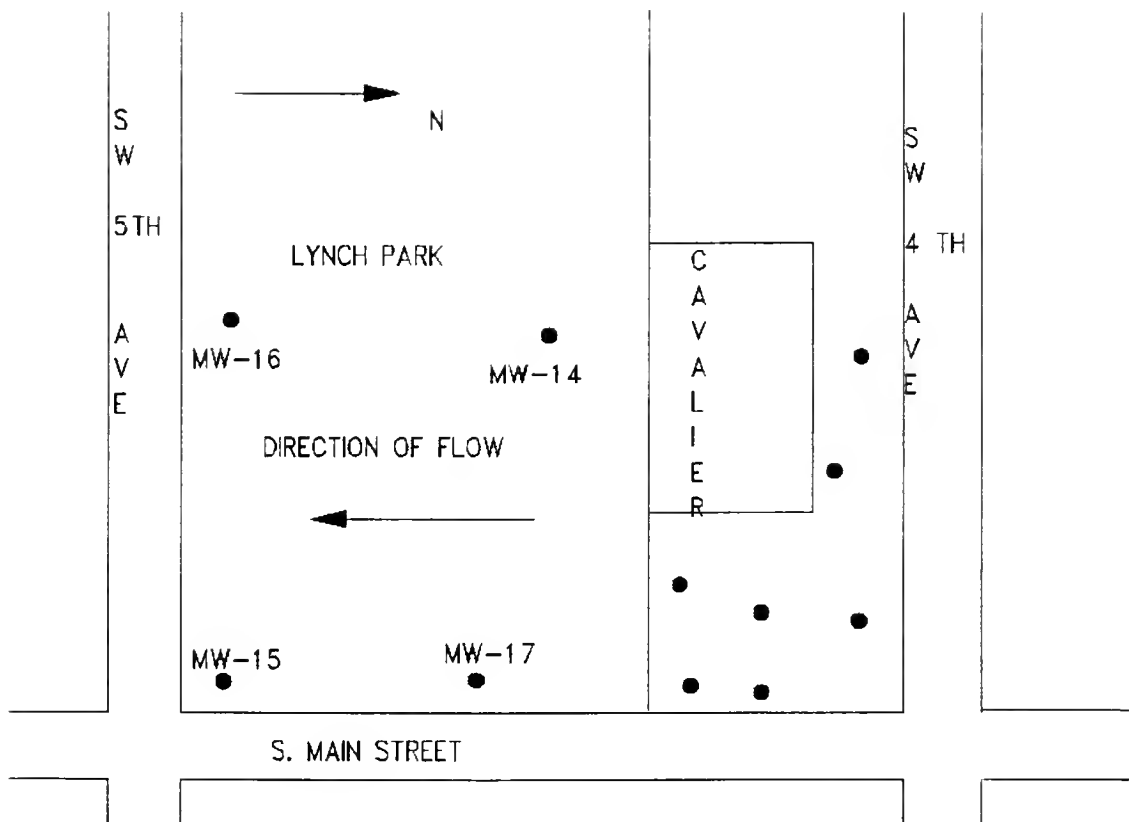


Figure 6.1 Cavalier Site Plan

probe with steel and HDPE filters were used to evaluate which filter type sorbed lower amounts of VOCs.

6.2 Field Test 1

Monitoring well MW-17 was purged by removing 3 well volumes of water with a three foot long teflon bailer. A one foot Teflon bailer was then used to obtain groundwater samples. The water was decanted from the bailer into 40 mL septum vials and stored in a cooler with ice packs. Four samples were obtained (BAILER1....BAILER4). The depth to the



Figure 6.2 View of Cavalier Site--Lynch Park on Left

water table in the well was approximately 9.5 feet. The smell of petroleum was prevalent when sampling.

BAT sampling was performed with the University of Florida's 20 ton electric cone penetration test truck positioned as closely as possible to the well. Since several obstacles (trees, shrubs, etc.) were present the proximity was severely limited. A BAT MK2 probe with a steel filter was pushed to a depth of 4 meters (13.1 feet) to obtain

groundwater samples. The probe was located 11.5 feet horizontally away from the well. After purging the probe, three 35 mL test tubes were filled using the cascaded sampling technique (BAT1, BAT3 and BAT5) which required more than thirty minutes per sample. The rods were then pulled, the truck moved slightly and a second penetration performed. This consisted of pushing a BAT MK2 probe with a HDPE filter to a depth of 3.5 meters (11.5 feet). This penetration was located 12.0 feet horizontally away from the well. One BAT sample (BAT7) without headspace was obtained at this location.

Chemical analyses were performed with a GC/MS in accordance with EPA Methods 524/624. Compounds specifically analyzed for were BTEX, trichloroethene (TCE), 1,2 dibromoethane (EDB), methyl tert-butyl ether (MTBE), and tetrachloroethene (PERC). Only BTEX was detected. Results are presented in Table 6.1.

6.3 Field Test 2

Additional testing at Lynch Park (Cavalier Site) was performed on 23 October 1991. The depth to the water table in monitoring well MW-17 was determined by two methods. Using a bailer, the depth to the water table was determined from hearing it touch the water level and measuring this distance. This gave a value of 9 feet and 6 inches. Using an electronic device (Soiltest, Inc., Model DR-760A Water level indicator) gave a water table depth of 9 feet and 11 inches.

The monitoring well was purged by removing three well volumes with a large Teflon bailer (1 L). While purging the well a strong hydrocarbon odor was quite prevalent. A small Teflon bailer (350 mL) was used for sampling. Two samples were pulled and two 40 mL vials were filled from each. These samples were designated BAILER1, BAILER2, BAILER3 and BAILER4 (which was not analyzed). BAILER1 and BAILER2 were obtained from the same bailer, as were BAILER3 and BAILER4. The samples were quite cloudy.

Distilled water was pulled through the BAT probe and placed in a 40 mL vial to serve as an equipment blank to ensure that no contamination remained from previous testing. The probe had been decontaminated with boiled distilled water after its previous use. The BAT probe was then penetrated 10 feet and 4 inches horizontally away from MW-17 and to a depth of 10.5 feet. This depth was chosen to ensure that the probe was extremely close to the actual water level where most of the BTEX compounds should be, since they are lighter than water. Before sampling, the pore pressure device was used to measure the pore water pressure at the BAT probe as another check on the water level. The digital readout gave a value of 0.1 meter. This meant that the probe was basically .1 m below the water table.

The BAT probe was purged twice before sampling. The first BAT cascaded sampling (BAT1) took 60 minutes and did not yield a full sample. A second cascaded sampling (BAT3), took

Table 6.1 Chemical Analyses from MW-17 at Cavalier Site

	Benzene ppb	Toluene ppb	Ethylbenzene ppb	Xylenes ppb
Water Table--9'-6"				
BAILER1	24	7198	3120	7880
BAILER2	20	4410	2606	6555
BAILER3	10	6724	3301	8048
AVG BAILER	18	6110	3009	7494
BAT Depth--13'-2"				
BAT MK2 probe with steel filter was located 11'-6" from MW-17.				
BAT1	0	72	25	68
BAT3	0	56	19	61
BAT5	0	21	29	5
AVG BAT	0	50	24	45
BAT Depth--11'-6"				
BAT MK2 probe with HDPE filter was located 12' from MW-17.				
BAT 7	0	31	29	9
All BAT samples contained no headspace				

40 minutes and also did not yield a full sample. A third sample was collected at this depth using a single test tube (BAT5) and had approximately 80% headspace.

The probe was then pushed down another meter to a depth of 13 feet and 1 inch. Water was purged from the probe before sampling. Two samples were obtained at this depth (BAT7 and BAT8). Each of these samples yielded only 1 mL of fluid. Time for each sample was 25 minutes.

All samples were iced at the site and then transferred to a refrigerator. No preservatives were used since the analysis would be performed within 7 days.

Chemical analyses were performed the following day with the GC/MS. In order to run these samples on the GC/MS, they had to be highly diluted since normally 20-30 ppb is the maximum level that should be run on this equipment. Some dilutions were made by placing 0.5 mL of the actual sample into 100 mL of deionized water. Other samples were more highly diluted by placing 0.5 mL of sample into 200 mL of deionized water. The concentrations of BTEX are given in Table 6.2. Ethylene dibromide (EDB) and methyl tert-butyl ether (MTBE) were not present in the groundwater samples. Trimethylbenzene was found but not quantitated. Naphthalene was present in both BAT and bailer samples. In the bailer samples the concentrations of naphthalene for the four samples were 479 ppb, 525 ppb, 599 ppb, and 672 ppb.

Table 6.2 Chemical Analyses from MW-17 at Cavalier Site

	Benzene ppb	Toluene ppb	EB ppb	Xylenes ppb	Headspace %
MW-17					
Water Table--9'-6" (measuring bailer) 9'-11" (electronic device)					
BAILER1	3	5591	2751	6684	
BAILER2	334	6470	2811	6698	
(Spiked Duplicate of 1)					
BAILER3	9	6084	2946	7597	
BAILER4	9	7912	2991	8127	
AVG BAILER		6514	2875	7277	
BAT Depth--10'-6"					
BAT MK2 with steel filter located 10'-4" from MW-17.					
BAT1	65	1426	148	478	60
BAT2	93	1920	232	720	60
BAT3	120	3060	601	1905	80
AVG BAT	93	2135	327	1034	
BAT Depth--13'-2"					
Same probe as above pushed to a deeper depth.					
BAT7	31	790	94	337	97

BAILER2 which was a duplicate of BAILER1 was spiked with a matrix of VOCs all at a concentration of 4 ppb. This matrix spike had been previously used that day for running

calibration checks of the GC/MS. Note that BAILER2 gave a significantly higher value of benzene present.

Comparing Tables 6.1 and 6.2 it can be seen that the concentrations in the bailer samples were approximately the same. The concentrations recorded for the BAT samples in Table 6.2 were substantially higher than those in Table 6.1 even though the former had tremendous amounts of headspace. If BAT samples would have contained no headspace they would have compared better with the bailer samples.

6.4 BAT Sampling Within MW-17

The water level in MW-17 was again determined by two methods in MW-17. The electronic device placed the water table at a depth of 9 feet and 10 inches while the bailer placed it at 9 feet and 8 inches.

Four well volumes were removed from the monitoring well with a Teflon bailer to purge it of stagnant water. A one foot long teflon bailer was then used to obtain water samples. From this one bailer, three samples (BAILER1, BAILER2 AND BAILER3) were placed into 40 mL vials using a teflon bottom emptying flow control valve. These samples were catalogued and placed in a cooler.

BAT sampling was then performed in the monitoring well. A BAT MK2 probe attached to 1 inch diameter pvc pipe was lowered down inside MW-17. PVC pipe was used in lieu of the steel drill rods due to the difficulty of lowering then

recovering the heavier steel rods. The center of the filter of the probe was lowered to a depth of 10 feet in order to keep it just below the measured water table. Two metal "C" clamps were placed around the 1 inch pvc pipe at a height of 10 feet in order to suspend the pipe at the required depth. Since the "C" clamps were larger than the 2 inch inner diameter of the monitoring well the pvc pipe was held firm to ensure the probe did not "fall" into the well.

The BAT probe was then purged of the distilled water which had been used to saturate it. Sampling was performed by the cascaded technique method. Four BAT samples were obtained without any head space (samples BAT1, BAT3, BAT5, and BAT7). These samples did, however, each have a small air bubble in them. BAT samples 2, 4, 6, and 8 were the corresponding duplicates of 1,3,5, and 7 which contained 25% head space. All samples were catalogued and placed in the cooler and then transported to the laboratory and maintained at 4 °C.

Lab blanks and calibration standards were run to ensure that the GC/MS was running properly and that the contaminants were within the control limits that had been established for the calibration standards. The samples were run in the following order: BAT1, BAILER1, BAT3, BAILER2, BAT5, BAILER3, BAT2, BAT4, and BAT6. Results are shown in Table 6.3. Generally, the BAT samples without headspace recovered more VOCs than did the Teflon bailer. This shows that there is not

Table 6.3 Chemical Analyses from BAT Sampling Within MW-17

	BENZENE ppb	TOLUENE ppb	ETHYLBENZENE ppb	XYLENES ppb	HEAD SPACE %
Water Table--9'-10" (electronic device) 9'-8" (measuring bailer)					
BAILER1	7	5494	2270	6146	
BAILER2	-	6147	2449	6583	
BAILER3	-	6631	2235	6801	
AVG BAILER		6091	2318	6510	
BAT MK2 probe with steel filter lowered inside MW-17 to a depth of 10'.					
BAT1	44	5700	2253	6282	0
BAT3	-	6602	2546	7220	0
BAT5	-	7514	2761	7742	0
AVG BAT		6605	2520	7081	
BAT2		6390	2015	6247	25
BAT4		6233	1862	6109	25
BAT6		8863	2547	8617	25
AVG BAT		7162	2141	6991	

a significant decrease in the recovery of VOCs in the BAT due to the initial negative pressure in the test tubes.

6.5 CPT Testing

An electric piezo cone was used at the Cavalier Products/Lynch Park site. Two soundings were made with the electric cone. The purpose of the soundings was to determine

the general soil stratigraphy at this site. Both soundings were stopped at a depth of approximately 15 feet. It was imperative that the soundings not cross a clay confining layer which could cause cross contamination into the lower aquifer.

The first sounding was made in the general vicinity of MW-17. The second sounding was made in the vicinity of MW-15. The results of the cone testing are shown in Appendix F. No clay was encountered in either sounding.

6.6 BAT Sampling Within MW-15

The water table depth in MW-15 was determined to be at a depth of 8 feet and 6 inches. The well was purged of four well volumes with the three foot long Teflon bailer. While purging the well some plastic cuttings and pine needles were retrieved in the bailer. The smell of aromatics and sulfur was present while purging the well. Water was then retrieved with the teflon bailer and decanted into two 40 mL vials (BAILER1 and BAILER2).

A BAT MK2 probe with a new HDPE filter was attached to one inch pvc pipe and lowered into MW-15. The top of the porous filter of the probe was placed at a depth of 8'-6". "C" clamps were used to maintain the required sampling depth. The BAT probe was first purged before sampling even though it was not pre-saturated. Two cascaded samplings were performed and yielded two full BAT sample tubes (BAT1 and BAT3) and two

partially filled tubes. Another bailer sample was then taken and two 40 mL vials filled (BAILER3 and BAILER4).

Three further cascaded samplings were performed (BAT5, BAT7 and BAT9). The average time for sampling was 6 minutes which yielded a full sample tube and an approximately 70% filled upper tube.

The analyses were performed on the GC/MS on in accordance with EPA Methods 524/624. The results of the analyses are shown in Table 6.4. Specific contaminants analyzed for were Benzene, Toluene, Ethylbenzene, and the Xylenes (BTEX). BAILER1 was the first sample tested but a quantitative analysis was not possible as the sample overloaded the GC/MS. Several blanks had to be run after this sample to clean the system before running any additional samples. All other samples were diluted by a factor of 100. Sample BAT9 was lost (froze and burst while stored in the refrigerator). The order of sample analyses was BAILER1, BAILER3, BAT1, BAT3, BAILER2, BAT5, and BAT7.

The bailer recovered higher amounts of VOCs than did the BAT MK2 probe. This is just the opposite of that found in Field Test 3 (Table 6.3). During this test the HDPE filter was not pre-saturated before sampling in the well. It is thought that a significant amount of sorption occurred in the HDPE filter. Samples BAT5 and BAT7 showed a significant increase in the levels of VOCs over samples BAT1 and BAT3. Since samples BAT5 and BAT7 were taken at a later time the

Table 6.4 Chemical Analyses from BAT Sampling Within MW-15

SAMPLE	TOLUENE ppb	ETHYLBENZENE ppb	M,P-XYLENES ppb	O-XYLENE ppb
Water Table--8'-6"				
BAILER2	395	910	1317	1265
BAT MK2 probe with HDPE filter placed at a depth of 8'-6" inside MW-15.				
BAT1	70	58	92	115
BAT3	84	72	114	140
AVG BAT	77	65	103	127.5
BAILER3	237	517	863	743
BAILER4	222	538	867	757
AVG BAILER	229.5	527.5	865	750
Same BAT MK2 probe with HDPE filter placed again inside MW-15 at a depth of 8'-6" for sampling.				
BAT5	205	220	368	403
BAT7	155	143	237	276
AVG BAT	180	181.5	302.5	339.5

HDPE filter probably had reached its sorptive capacity of these VOCs and allowed a more representative sample to be collected.

A possible cause of the disparity in results is that the bailer and sample vials are exposed to the atmosphere while the BAT sample vials are hermetically sealed and do not allow any atmospheric contamination. The well sampled (MW-15) was located within 10 feet of South Main Street in Gainesville

where there is considerable automobile traffic. This makes it very likely that the bailer and sample vials could be contaminated with gasoline constituents (BTEX) while sampling.

6.7 BAT Field Test 5

Testing was performed at the site in conjunction with an "insitu" lab course taught by the civil engineering department at the University of Florida. The purpose was to familiarize students with the BAT groundwater monitoring system.

A BAT MK2 probe with a steel filter was hydraulically pushed to a depth of 11 feet. It was not presaturated with water before insertion. The probe was located 15 feet southeast of MW-17. A test tube was used to pull formation water into the filter and the test tube. The test tube was opened and aromatic vapors were present. A single test tube sampling was then performed. It yielded a sample of 24 mL in 24 minutes (BAT1). A cascaded sampling was then performed for 33 minutes. The bottom sample tube had approximately 35 mL (BAT3). Since the tube holds 36 mL no water entered the upper tube.

A pore pressure reading was then made to determine the depth to the water table. The pore pressure reading was .68 meters (2'-3"). This put the water table at a depth of 8'-9". An inflow permeability test was performed next. This test yielded a sample of 22 mL in 34 minutes (BAT4). The coefficient of permeability was calculated to be 3.1E^{-07} cm/sec. The data sheet is shown in Appendix A. From the CPT

testing performed previously (Appendix F), the soil at this depth classified as a sand to silty sand. This permeability value should be that of the soil since it is considerably lower than the permeability of the filter $1E^{-04}$ cm/sec. The value calculated is lower than the typical permeability of a silty sand. It is more indicative of a clay soil.

The depth to the water table in MW-17 was then determined by use of the electrical conductivity/resistivity meter. It yielded a depth to the water table of 9'. The water table was also checked by lowering a teflon bailer down the well until it touched the water surface. This also gave a value of 9'. This was in general agreement with that determined with the BAT pore pressure device.

While performing the permeability test, MW-17 was purged by use of a Teflon bailer. There was a strong odor of hydrocarbons while purging the well. The same bailer was then used to fill 2-40 mL vials (BAILER1 and BAILER2).

A second pore pressure reading taken from the BAT system gave a value of .63 meters. A second inflow permeability test was performed. It yielded a sample of 18 mL in 32 minutes (BAT5). All samples were placed in a refrigerated cooler immediately upon retrieval. The coefficient of permeability was calculated to be $2.7E^{-07}$ cm/sec (Appendix A).

The chemical analyses were performed on the GC/MS in accordance with EPA Methods 524/624. The results are shown in Table 6.5. All samples had to be diluted to avoid overloading

Table 6.5 Chemical Analyses from Lab Insitu Class

SAMPLE	BENZENE	TOLUENE	ETHYL- BENZENE	M,P XYLENE	O-XYLENE
BAT Depth--11'					
BAT MK2 probe with steel filter located 15' from MW-17.					
BAT1 (35% Head space)	22.6	708	375	390	330
BAT3 (1% Head space)	22.0	400	296	279	219
BAT4 (39% Head space)	20.6	237	222	186	138
BAT5 (50% Head space)	22.6	217	210	172	136
AVG	21.9	391	276	257	206
Water Table--9'					
BAILER1	22.2	3231	1849	1943	2530
BAILER2	19.8	4236	2090	2508	2789
AVG	21.0	3734	1970	2226	2660

All values are in ppb.

the GC/MS. Samples were diluted by a factor of 100 except BAILER2 which was run at a dilution factor of 200. Trimethylbenzene was also detected but not quantitated.

There was little difference in the recovery of benzene between the bailer and the BAT, but there was a considerable difference in the other contaminants (toluene, ethylbenzene, m,p-xylene, and o-xylene). The bailer generally recovered 10 times as much. This again was probably due to the sampling at

different depths. BAT samples were obtained at a depth of 11 feet while the bailer was used at 9'. When free product is present at a site its thickness in a monitoring well is greater than what actual exists since the product floats on top of the capillary fringe which is higher than the water table in the monitoring well. BAT samples with less headspace recovered more VOCs. Note that the BAT samples taken before purging the monitoring well were also higher than those obtained afterwards. By purging the well it may have pumped less contaminated water to the BAT probe.

6.8 Summary

Testing with a BAT MK2 probe (steel filter) inside MW-17 showed that the BAT groundwater monitoring system could recover higher concentration levels of VOCs than the bailer. Use of a BAT MK2 probe (HDPE) inside MW-15 showed a lower recovery of VOCs than the bailer due to sorption on the HDPE filter. BAT samples obtained from the soil did not compare favorably with those from the monitoring wells due to the different depth at which the BAT was used to sample. Another factor was the horizontal distance that the BAT probes were placed from the monitoring wells due to vegetation (trees, shrubs etc.).

CHAPTER 7 FIELD STUDIES--TEXTILE TOWN

7.1 Introduction

Field testing was performed at the Textile Town site (formerly a Fina gas station) in Micanopy, Florida. The site is located off of Interstate Highway 75 (exit 73) and State Route 234. Monitoring wells had been installed at this site by Geosolutions, Inc. of Gainesville, Florida. Figure 7.1 is a plan of the site showing the locations of facilities and of the monitoring wells. Figure 7.2 is a photo of Textile Town.

Testing was performed at this site to allow the penetrometer truck to be placed closer to existing monitoring wells. This allowed better comparison of the recovery of VOCs from samples obtained with the BAT probe and the Teflon bailer. One objective at this site was to demonstrate that the BAT probe could be useful in determining the horizontal and vertical extent of contamination. Another objective was to show that the BAT testing was repeatable by making multiple punches in the ground and obtaining samples with nearly the same levels of contamination.

Sampling in monitoring wells was performed after the standard procedure of removing three to four well volumes with

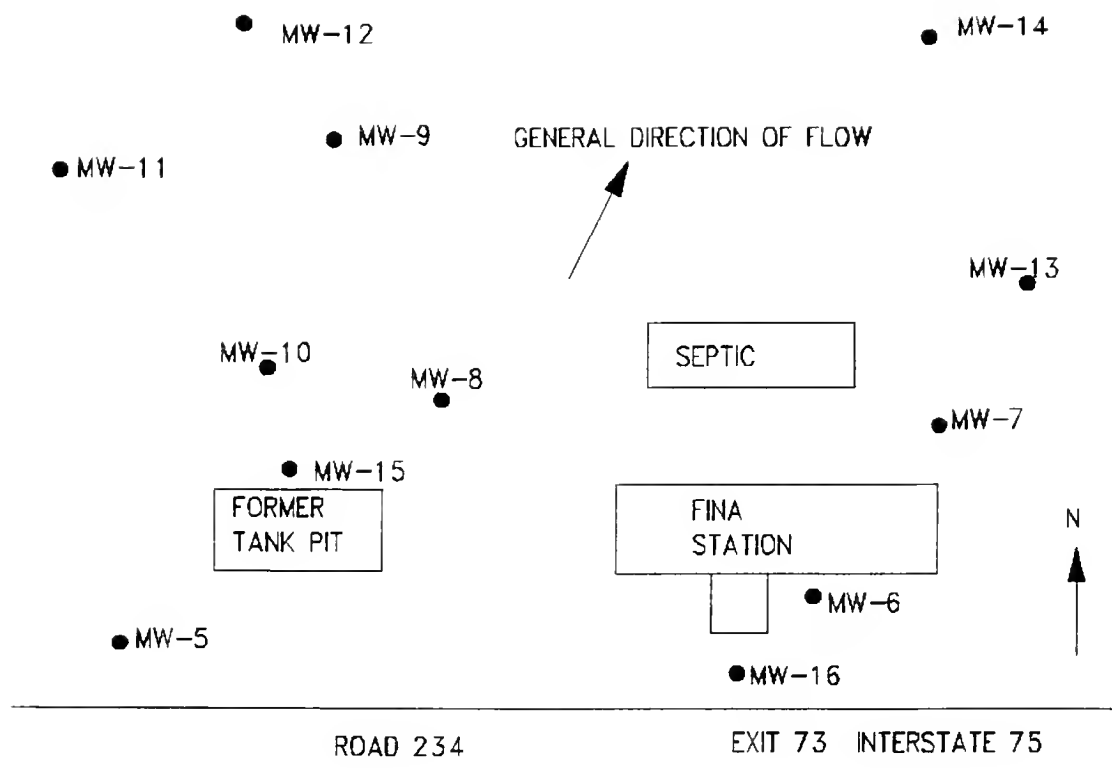


Figure 7.1 Textile Town Site Plan

a bailer. All samples were refrigerated at 4 °C until analyses were performed on the GC/MS in accordance with EPA Method 524/624.

7.2 BAT Test 1

Monitoring well number 11 (MW-11) was used for this test. It is shown in Figure 7.3. This well had shown concentration levels of tetrachloroethene (PERC) near 100 ppb the previous month. The water table, measured by three different devices (two electronic devices and by the bailer), was located at a



Figure 7.2 View of Textile Town--Penetrometer Rig near MW-7

depth of 6 feet. A one foot bailer was used for two samplings. Two 40 mL vials (Samples BAILER1, BAILER2 and BAILER3, BAILER4) were filled from each bailer using the bottom flow control valve.

The penetrometer rig was placed adjacent to MW-11 and a BAT MK2 probe was pushed to a depth of 6 feet 6 inches. The sounding was 5 feet horizontally from MW-11. Several attempts were made to purge the probe but only 5 mL of water was



Figure 7.3 Cone over MW-11

obtained. The probe was then pushed to a depth of 3 meters (9 feet 10 inches) to see if the additional hydraulic head would allow sampling. Approximately 3 mL of water was obtained from several attempts. The filter either had become clogged with fine particles or had lost its saturation while being deployed.

The drill rods were pulled and a second BAT MK2 probe was pushed down the same hole to a depth of 6 feet 6 inches. Several attempts were made to purge this probe but only around

5 mL of water was obtained. The drill rods and probe were pulled and the penetrometer rig moved forward approximately one foot.

The Enviro probe was then pushed to a depth of 6 feet 6 inches. The drill rods were pulled up 4 inches to allow the shielded probe to become exposed to the groundwater. Again, only small amounts of water were retrieved with each sampling attempt.

7.3 BAT Test 2

A BAT MK2 probe with steel filter was pushed to a depth of 7 feet 4 inches. The sounding was located 12 feet horizontally from MW-11. The pore pressure reading device gave a negative pressure of $-.44$ meters. This indicated one of three things: the probe was above the water table (unsaturated zone), the probe was below the water table but had lost saturation, or the soil was a dense clay and negative pore pressures had been generated when inserting the probe into the ground. Two test tubes with water were pressurized and sent down to the probe to help resaturate the probe. Water was injected into the probe and the soil. An evacuated test tube then was sent down but only retrieved 2 mL of water.

This same probe then was pushed to a depth of 8 feet 6 inches. A test tube was sent down for 7.5 minutes and recovered 10 mL of water. This was sufficient to purge the probe. The next test tube recovered approximately 8 mL of water after 19 minutes and the following recovered 8 mL in 33

minutes. The drill rods and probe were retracted and the penetrometer rig was moved to a new location 5 feet from the well.

The Enviro probe was pushed to a depth of 8 feet 6 inches. The probe was purged twice, each time for 4 minutes, and recovered 10 and 15 mL of water respectfully. Cascaded sampling was then performed. The first sample recovered approximately 30 mL of water in the bottom test tube in 29 minutes. The second sample recovered the same amount in 22 minutes. Both samples had approximately 10 to 15 percent head space.

Chemical analyses were performed on 3 BAT samples and two bailer samples. BTEX was not present in any of the samples. Tetrachloroethene (PERC) was observed in both bailer samples but not in the BAT samples. The two bailer samples had concentration of 28 and 26 ppb respectively. The BAT samples were taken at a depth of 8 feet 6 inches while the bailer samples were taken at the water table (6 foot depth). Even though tetrachloroethene is heavier than water, if in small concentrations it will dissolve into the water and move with the groundwater flow. If a tank full of pure tetrachloroethene had leaked into the ground the contaminant would move vertically through the groundwater due to gravity until it reaches a confining layer. Since the concentrations were small it is not unreasonable that the BAT did not detect any PERC since it was 2.5 feet below the water table. By

purging the monitoring well with the Teflon bailer considerable mixing occurs. This mixing could bring tetrachloroethene up from the bottom of the well.

7.4 BAT Testing at MW-7

Testing was performed around MW-7 which had previously shown concentrations of BTEX. Figures 7.4 and 7.5 show the penetrometer truck around MW-7. The depth to the water table was measured at 7 feet 6 inches. A small bailer was used for sampling. Two samples were taken from two bailers for a total of 4 samples (BAILER1 and BAILER2 were from the same bailer and BAILER3 and BAILER4 likewise).

The BAT MK2 probe then was pushed beside the well but no samples were obtained. Either the needles were not making good connection with the bottom septum of the BAT or the bottom septum of this BAT had deteriorated and needed replacing.

The Enviro probe then was pushed to a depth of 8 feet 2 inches. This placed the bottom of the filter at 7 feet 7 inches. The sounding was located 8 feet horizontally from the well. The probe was purged of the water used for saturation. Two cascaded sampling attempts were made. The first sampling yielded a full bottom test tube (BAT1) and an upper test tube 80% filled (BAT2). This sampling took 21 minutes. The secondsampling attempt yielded the same results in 6 minutes (BAT3 no headspace, BAT4 headspace). The rods were then



Figure 7.4 View of Stripping Tower for Remediation retracted and the penetrometer rig moved to allow another penetration.

The second BAT MK2 unit then was pushed to a depth of 7 feet 11 inches which placed the filter at 7 feet 9 inches. This sounding was 6 feet from the well. The probe was purged before sampling. The first cascaded sampling attempt yielded the bottom test tube approximately 90% filled in 24 minutes (BAT5). The second attempt yielded the bottom test tube only 60% filled in 32 minutes (BAT7).

Results of the chemical analyses are shown in Table 7.1. Again the bailer showed higher concentrations than did the



Figure 7.5 Penetrometer Rig around MW-7

BAT. This is most likely due to the fact that a monitoring well is screened over a large vertical interval while the BAT samples at a discrete depth (filter length 2 to 4 inches). When a well is purged a significant mixing of water takes place. It is therefore more likely to obtain some contaminated water when sampling. The BAT could be used to determine the vertical extent of contamination to determine the depth to where the maximum level of contamination occurs. This type of testing was performed next.

Table 7.1 Chemical Analyses from MW-7 at Textile Town

	BENZENE ppb	TOLUENE ppb	ETHYLBENZENE ppb	XLENES ppb
Water table Depth--7 feet 6 inches				
BAILER1	107	49	45	85
BAILER2	49	0.3	15	7.8
BAILER3	65	0	0	0
BAILER4	0	0.3	13	7.7
AVG BAILER	55	12.4	18.3	25.1
Enviro probe (HDPE filter) Depth of filter 7 feet 7 inches				
BAT1	0	0.6	0.1	0.6
BAT3	0	1.2	0.5	1.7
BAT MK2 probe (HDPE filter) Depth of filter 7 feet 9 inches				
BAT5	0.1	0.8	0.3	1.3
AVG BAT	0	0.9	0.3	1.2

7.5 Vertical Contamination Profile at MW-7

On 6 December 1991 additional testing was performed around MW-7 at the Textile Town site in Micanopy, Florida. A BAT MK2 probe was pushed down 6 feet from MW-7 to a depth of 9 feet. Previous testing with the BAT had been performed around MW-7 at a depth of approximately 8 feet and had yielded small concentrations of BTEX (see Table 7.1). After purging

the probe at the 9 foot depth a sample was obtained. Since there was no odor of gasoline this sample was discarded.

The same probe then was pushed to a depth of 10 feet, purged and sampled (BAT1), then to 11 feet, purged and sampled (BAT2). This later purge water smelled of gasoline. Sampling was also performed at the 12 foot depth (BAT4) after purging. This purge water also smelled of gasoline (BAT3). At 13 feet only 2 mL of water could be purged from the filter in 7 minutes which meant the probe was probably in low permeability soil. No odor was present in this water. The rods then were retracted, the penetrometer rig moved and another push was made.

The Enviro probe was pushed 7 feet from MW-7 to a depth of 11 feet. The filter was not saturated before insertion. The purge water was then actual formation water. This purgewater smelled of gasoline. Two samples were then obtained at this depth (BAT7 and BAT8). Chemical analyses were performed on 9 December 1991. Results of chemical analyses from this round of testing are shown in Table 7.2. Figure 7.6 shows a profile of the vertical extent of contamination around MW-7.

7.6 Vertical Profile Testing at MW-11

On 10 December 1991 additional testing was performed at MW-11 to evaluate the vertical extent of tetrachloroethene (PERC). The water table level in the well was measured at 6 feet 6 inches. Four bailer samples were decanted into 40 mL

Table 7.2 Chemical Analyses of Vertical Sampling at MW-7

	BENZENE ppb	TOLUENE ppb	EB ppb	XYLENES ppb	HEAD SPACE %	DEPTH feet
Sampling 6 feet horizontally from MW-7 BAT MK2 probe with HDPE filter						
BAT1	2.4	ND	ND	ND	57	10
BAT2	18.0	1.0	1.5	2.2	14	11
BAT4	38.0	0.8	0.7	1.4	0	12
BAT3 (Composite-purge for BAT4)	22.7	1.1	0.8	1.6	52	11-12
Sampling 7 feet horizontally from MW-7 Enviro probe with HDPE filter						
BAT7	20.8	0.9	0.3	0.9	1	11
BAT8	24.3	1.3	0.4	1.2	0	11
Depth 11 feet (BAT2, BAT7, BAT8)						
AVG	21.0	1.1	0.7	1.4		
STD DEV	2.6	0.2	0.5	0.6		
REL STD	12.4	18.4	71.4	42.9		

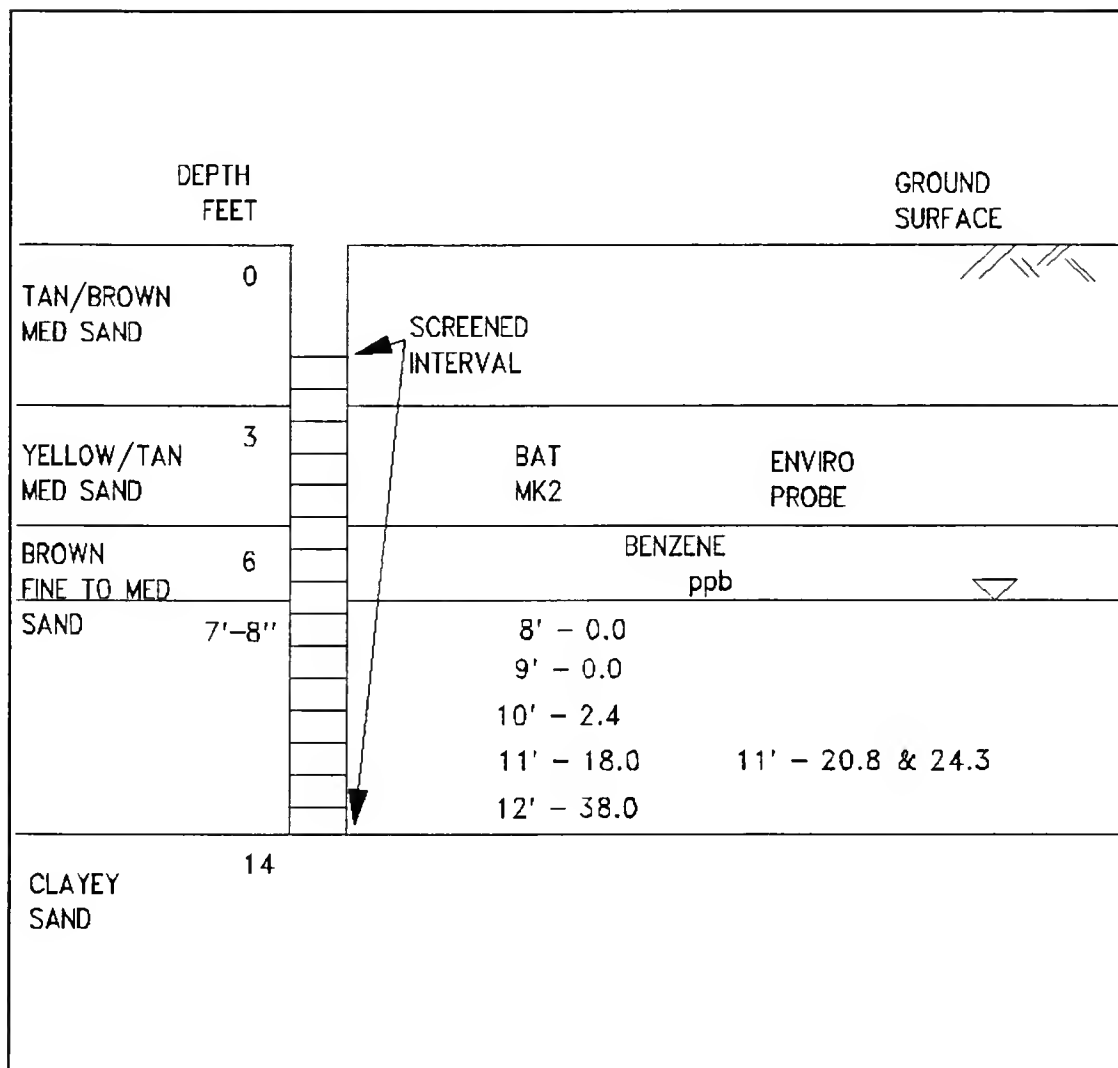


Figure 7.6 Vertical Contamination Profile at MW-7

vials, two samples from each bailer (BAILER1 and BAILER2 correspond as do BAILER3 and BAILER4).

The BAT MK2 probe with a HDPE filter was pushed 6 feet from MW-7 on the down gradient side and to a depth of 7 feet. Samples were taken at one foot depth intervals from 7 to 13 feet.

Sample analyses were performed with the GC/MS and no contamination of PERC was detected in the BAT samples. The two bailer samples from the monitoring well that were analyzed showed concentrations of 21.7 and 20.5 ppb. Figure 7.7 shows a Profile of MW-11.

7.7 BAT Probe Testing in MW-11

On 17 December 1991 additional testing was performed at the Textile Town site around MW-11. Previous BAT testing around this well did not recover any PERC while bailer samples from the well did. This testing consisted of lowering a BAT probe down inside the monitoring well to show that the BAT could recover PERC. If the BAT did recover PERC from the well then it meant that the previous testing with the BAT was valid, simply there was no contamination at the discrete locations sampled.

The water table was first determined to be at a depth of 6 feet 9 inches. Two bailers were retrieved and two samples were decanted from each bailer into 40 mL vials (BAILER1 and BAILER2 correspond as do BAILER3 and BAILER4).

A BAT MK2 probe with a steel filter was attached to pvc pipe and lowered down inside MW-11 to a depth of 7 feet where it was suspended using "C" clamps. The probe was purged for 30 seconds yielding a test tube of 30 mL of water. Cascaded sampling was then performed. Two full samples (BAT1 and BAT3)

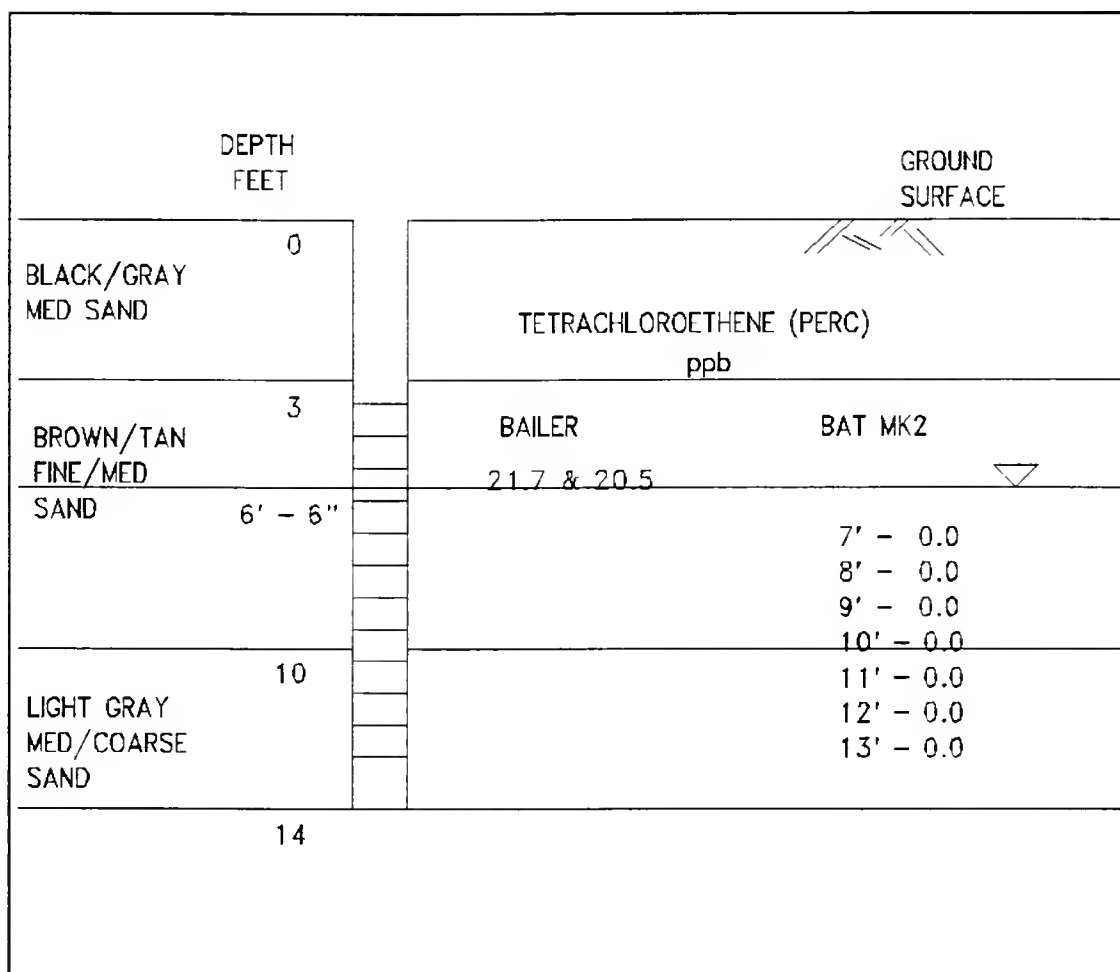


Figure 7.7 Vertical Contamination Profile at MW-11

without headspace were obtained at this depth. The time for sampling was three minutes. The upper test tubes had approximately 25-30 mL of water.

An additional length of pvc pipe was added and the probe lowered to a depth of 10 feet where it was purged. One cascaded sampling was performed at this depth (BAT5). The probe was then lowered again and sampled (BAT7). This time the top of the filter was placed at a depth of 12 feet 2

inches and the bottom at 12 feet 4 inches. The bottom slot of the well was located at 12 feet 3.8 inches. The bottom slot of the well is the deepest location where water can enter the well. Since PERC is heavier than water, it was hoped that it would be present at this depth.

If pure PERC is leaked or spilled into the ground it will fall through the groundwater since it has a higher specific gravity than water until it reaches a confining layer. Since it is immiscible (low solubility) it will remain in a separate phase. PERC is considered a dense non-aqueous phase liquid (DNAPL). Once it reaches a confining layer the PERC will move with gravity down any slope. If the confining layer is relatively horizontal the pure PERC will remain essentially stationary. Some will with time dissolve into the ground water and move with it. Because of this slow dissolution of the PERC it can show up at the monitoring well for a long period of time. When PERC is reduced it becomes vinyl chloride.

Chemical analyses are shown in Table 7.3. The bailer recovered slightly higher concentrations of PERC than did the BAT. However, the BAT was a more precise device as it yielded a lower standard deviation and relative standard deviation.

7.8 Plume Chasing

BAT testing was performed at the Textile Town site to try to determine a portion of the contaminant plume around MW-7.

Table 7.3 Analyses from BAT Testing in MW-11

TETRACHLOROETHENE (PERC)	
	ppb
BAILER1	23.8
BAILER3	20.5
BAILER4	25.0
AVERAGE	23.1
STD DEV	1.9
RSD	8.2%
BAT1--7'	17.2
BAT5--10'	17.8
BAT7--12'	16.1
AVERAGE	17.0
STD DEV	0.7
RSD	4.1%

Testing performed six days earlier with the BAT seven feet north of MW-7 gave benzene concentrations around 26 ppb.

The purpose of the testing was to gradually move away from MW-7 in the down gradient direction and determine how far the benzene contamination had extended. Since three BAT probes were available, three separate penetrations were possible without having to decontaminate the probes. Since testing earlier in the week had been performed a distance of 7 feet from the well, the first new BAT penetration was made using the Enviro probe at a distance of 14.5 feet. Sampling was performed at a depth of 11 feet 6 inches from the surface. A full sample was obtained in 32 minutes (BAT1).

After sampling at the first location the rods were pulled, the truck lowered from its hydraulic supports, and moved to a distance which was 27 feet 6 inches away from MW-7. A BAT MK2 probe with a steel filter was pushed to a depth of 11 feet for sampling. A sixty minute cascaded sampling yielded a full lower test tube (BAT3) and approximately 12 mL in the upper tube.

The third BAT sounding was performed 35 feet north of MW-7. A BAT MK2 probe with a HDPE filter was pushed to a depth of 11 feet. A cascaded sampling yielded a full test tube (BAT5) and approximately 8 mL of another in 67 minutes.

In just 6 hours a single operator was able to sample at three locations and obtain a sample without headspace from each. All penetrations were made without first saturating the porous filters of the probes. The Enviro probe required less time to sample. This is either due to its larger filter area or to the fact that the filter is shielded when being deployed and thus protected from becoming clogged with fine material.

The results of the chemical analyses are shown in Table 7.4. Trace amounts of toluene and xylene were found (usually less than 0.2 ppb). Figure 7.8 shows the lateral plume delineation.

7.9 CPT Testing

On 30 January 1992 two electric piezo cone soundings were performed at the Textile Town site to determine the soil

Table 7.4 Chemical Analyses from Plume Chasing

	SAMPLING DEPTH ft	DISTANCE FROM MW-7 ft	BENZENE ppb
BAT1 (No headspace)	11.5	14.5	3.5
BAT2 (10% headspace)	11.5	14.5	3.0
BAT3	11.0	28.0	0.0
BAT5	11.0	35.0	0.0

stratigraphy. Contaminants will migrate more quickly through soil layers having large coefficients of permeability (sand and gravel).

One sounding was performed in the vicinity of MW-7 and the second in the vicinity of MW-11. Soils were identified primarily as sands to silty sands. Clay was not encountered in either sounding. Soundings were made to a depth of approximately 15 feet. It was imperative that they not cross the soil confining layer which could allow cross contamination from the surficial aquifer into the confined aquifer. Cone penetration data are presented in Appendix F.

7.10 Summary

BAT probe testing was proven to be useful in determining both the horizontal and vertical extent of groundwater

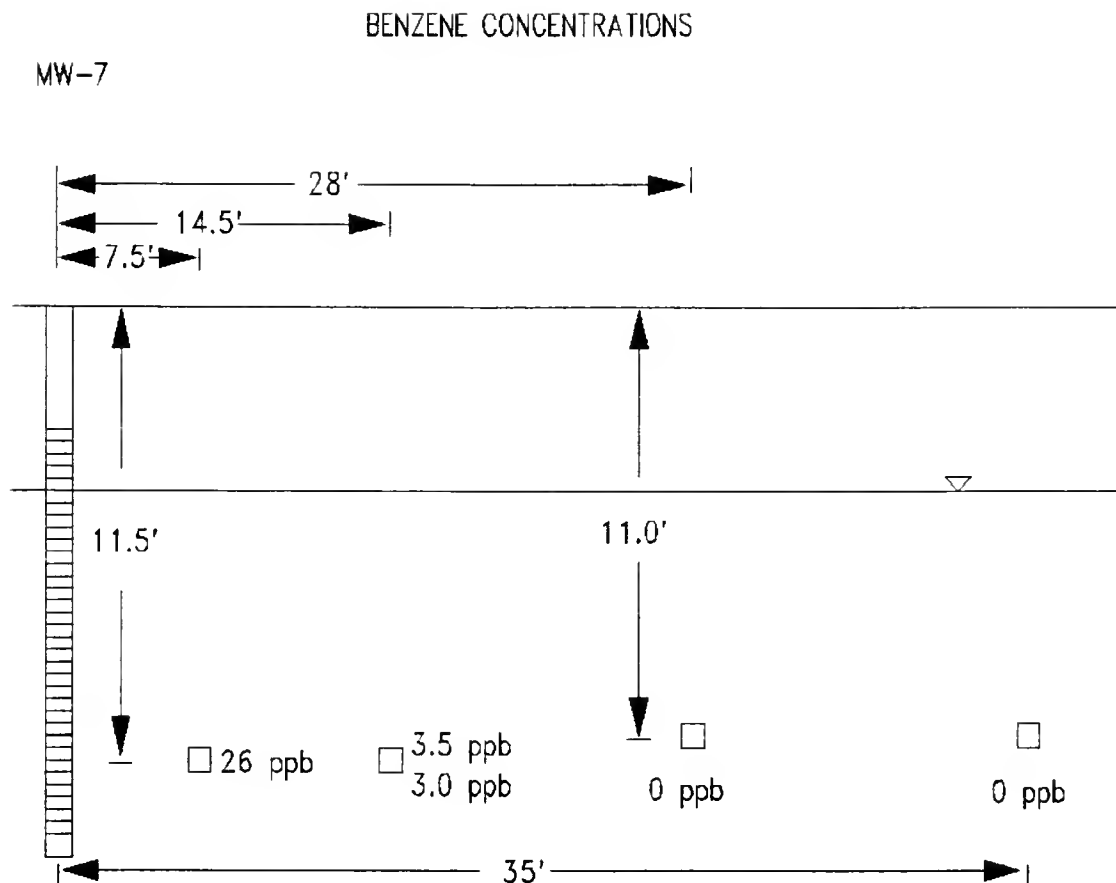


Figure 7.8 Lateral Plume Delineation

contamination at a site. While determining the vertical extent of contamination around MW-7 an additional probe sounding was made and the results showed that testing with the BAT probe can be highly repeatable. Sampling with the BAT probe inside MW-11 recovered slightly lower concentration levels of PERC than did the bailer, however, the BAT proved to be more precise by showing a lower standard deviation and relative standard deviation in the data.

CHAPTER 8 BAT MODIFICATION TESTING

8.1 Vacuum Pump Test 1

One disadvantage of the BAT system is that it retrieves only a relatively small sample, 35 mL in a single sample test tube and 70 mL in a cascaded sample. In order to obtain a larger sample the BAT system was modified to allow continuous sampling using a vacuum pump.

The design was to function in a manner similar to that used with peristaltic pumps. The idea was to place tubing from a vacuum pump through a rubber stopper into a Erlenmeyer flask. A second length of tubing would pass from the flask down the drill rods and make connection with the BAT probe. When the vacuum pump was running it would pump water up through the tubing and deposit it into the flask where it could be transferred into 40 mL vials for storage and transportation.

Flexible quarter inch diameter tubing was used so that it could be run through the existing BAT weight chain. A Swagelok, was attached to the end of the tubing and a brass adaptor made to connect the swage lock to the existing BAT pore transfer nipple. A needle was placed at the end of the

pore transfer nipple which was covered by the existing BAT guide sleeve (Figure 8.1).

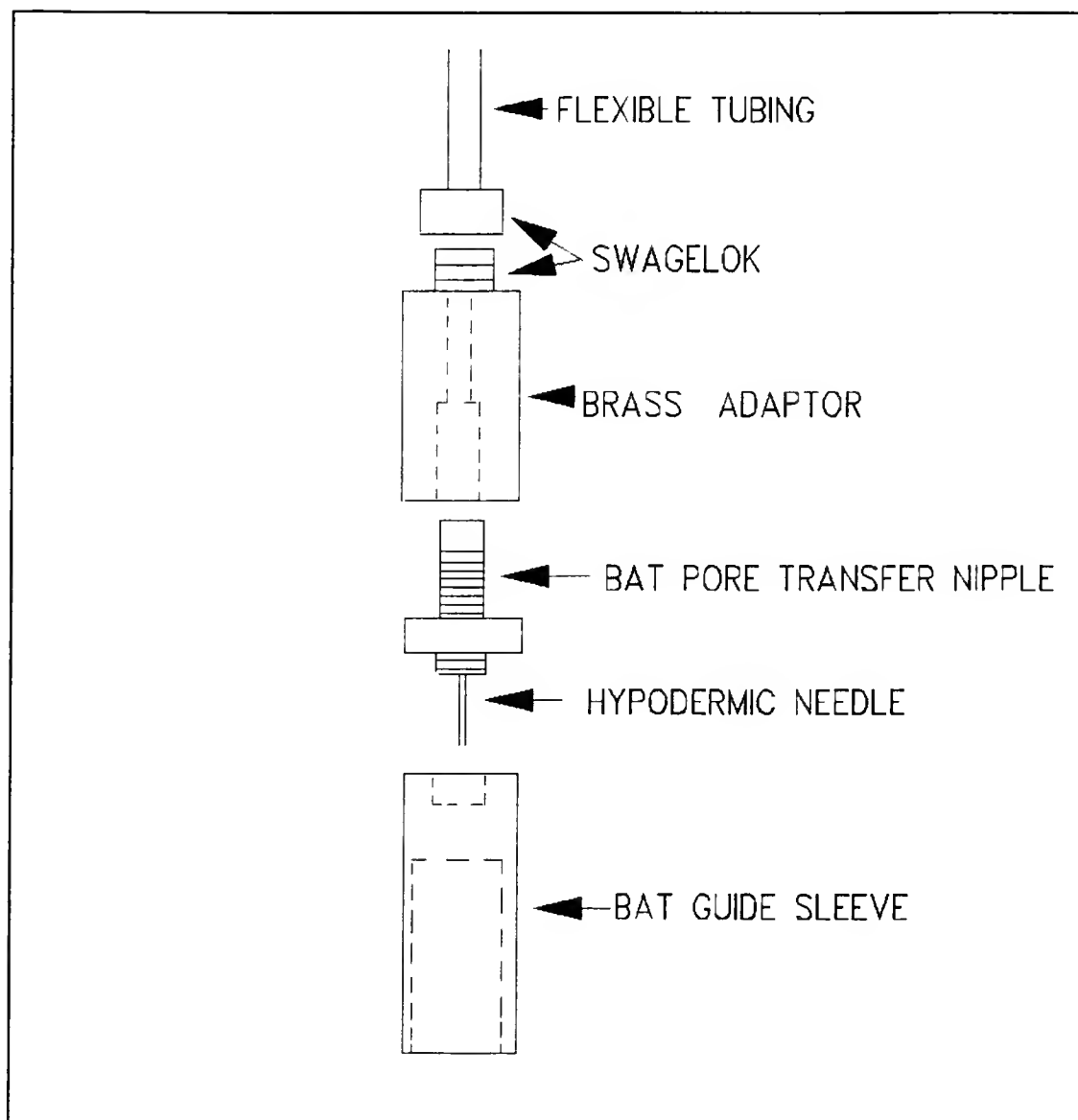


Figure 8.1 Brass Adaptor for Vacuum Pump Testing

The depth to the water table in this well was 7 feet 7 inches. The well was purged of four well volumes and then

sampled. Samples BAILER1 and BAILER2 were obtained from one bailer. Sample BAILER3 was obtained from a second bailer. All samples were decanted from the top of the bailers. While bailing the well, a gasoline odor was noticeable.

The BAT Enviro probe was penetrated 7 feet north of MW-7 and pushed to a depth of 11 feet 6 inches. Previous sampling at this depth had yielded benzene concentrations around 23 ppb (see Section 7.6). The Enviro probe was not saturated before insertion. One test tube was lowered down to saturate the probe. A cascaded sampling was then attempted. Sampling for ten minutes yielded a lower test tube 65% filled (BAT1). The next cascaded sampling attempt was left for 28 minutes. This yielded a full lower sample plus another test tube 50% filled. A third cascaded attempt yielded essentially identical samples in 26 minutes (BAT5).

After this conventional sampling with the BAT, the vacuum pump apparatus was used. The modified adaptor was lowered down the drill rods and once connection was made to the probe the vacuum pump was started. The vacuum pump was plugged into one of the 110 volt sockets in the CPT truck powered by its generator. The vacuum pump was a 60 HZ, 1/3 HP, unit manufactured by Precision Scientific Group of Chicago, Illinois. After a minute of pumping, water began being deposited into the flask. One problem was there was considerable air in the tubing which caused bubbling. These bubbles caused a lot of turbulence in the water as it was

deposited into the flask. The collected water was thrown out. It is known that suction type devices cause volatiles to be pulled out of the water into a gaseous phase and lost to the atmosphere. For this reason, regulatory agencies generally do not allow peristaltic pumps to be used for sampling volatiles. Another disadvantage of using a vacuum pump is that water can only be pumped a maximum of 33 feet. This method could however be applicable for the shallow sampling of other contaminants that are not volatile, such as heavy metals.

A possible modification to the system would be to remove the rubber septum in the BAT probe and place tape temporarily over the end to keep water from entering the drill rods. Once the probe was pushed to the sampling depth a needle could be lowered down the well to puncture the tape and allow water to enter the drill rods. The vacuum pump could then be used without the necessity of the needle in the bottom. Another possibility, instead of using the vacuum pump, would be to lower a small diameter (less than one inch) Teflon bailer down the drill rods and obtain samples. This would be similar in nature to the Hydropunch method.

Chemical analyses were performed on the GC/MS on 9 January 1992. Results, in Table 8.1, show that the BAT recovered higher concentrations of benzene than did the bailer. The average BAT value of 29.9 ppb is of the same order of magnitude as was recovered at the same depth a month before (Section 7.6). The BAT recovered small concentrations

(less than 1 ppb) of toluene, ethylbenzene and the xylenes while the bailer did not detect any.

8.2 Vacuum Pump Test 2

On 10 January 92, a second series of field tests using the vacuum pump apparatus and conventional BAT sampling was performed at the Micanopy Textile Town site. No well sampling was performed. The probe was placed 7 feet 7 inches from MW-7 and pushed to a depth of 11 feet 6 inches.

To get an idea of the time required to retrieve a sample, the setup and testing procedures were timed. These times reflect the ability of a single operator trained to use the penetrometer rig and the BAT groundwater monitoring system and for this particular site. Table 8.2 includes the results of this study.

Initially two conventional cascaded samplings (BAT1 and BAT3) were performed. The vacuum pump apparatus then was used to sample the groundwater. First the tubing was purged for 5 minutes and this water discarded. Water was then collected in a Nalgene Erlenmeyer flask for 15 minutes. Finally, samples were decanted from the flask into 40 mL vials and refrigerated.

The vacuum pump was used again to collect water but this time into a glass Erlenmeyer flask. This was to see if there was any sorption on to the Nalgene flask. The pump was used

Table 8.1 Chemical Analyses from MW-7

BENZENE ppb		
Water Table Depth - 7 feet 7 inches		
BAILER1	4.1	
BAILER2	3.1	
BAILER3	5.4	
AVG BAILER	4.2	
Depth - 11 feet - 6 inches		Head Space
BAT1	25.8	0
BAT3	24.7	0
BAT5	39.2	0
AVG BAT	29.9	

for 6 minutes and retrieved 100 mL in the flask. One final conventional BAT cascaded sampling (BAT5) was performed to obtain a full sample. Results of the chemical analyses are shown in Table 8.3.

Upon returning to the laboratory it was decided to try another modification to the equipment. This consisted of removing the septum nut and the rubber septum from the BAT MK2

Table 8.2 Total Times for Truck Set Up and Sampling

Total Running Time	Operation
5 minutes	Truck started and leveled
18 minutes	Enviroprobe pushed to a depth of 11 feet 6 inches
25 minutes	BAT equipment assembled for sampling and purging initiated
30 minutes	Purging complete and sampling initiated
53 minutes	Cascaded sampling completed One full 35 ml sample and one sample 65% filled obtained
1 hour 20 minutes	Two full samples obtained from cascaded sampling

probe. A piece of Scotch tape was placed over the top of the probe to keep water out of the drill rods. The probe was then lowered into the large nalgene tank filled with water. A single BAT test tube was lowered down the drill rods. Upon connection the needle penetrated the tape and the test tube filled with water. When the sampling adaptor was removed from the drill rods, water continued to enter the drill rods since the tape seal had been broken. Water quickly filled the drill

Table 8.3 Chemical Analyses from Vacuum Pump Apparatus

BENZENE ppb	
Vacuum flask apparatus - sampling depth 11.5 feet	
NALGENE FLASK	1.2
GLASS FLASK 1	0.9
GLASS FLASK 2	0.8
AVG	0.97
BAT cascaded sampling - sampling depth 11.5 feet	
BAT1	23.3
BAT3	16.6
BAT5	37.6
AVG	25.8

rods. It was expected that this water could then be sampled with a small Teflon bailer.

On 12 February 1992 a one foot long, 3/4" diameter Norwell Teflon bailer (60 cc capacity) was obtained and the above described test performed in the lab. Nylon string was tied to the bailer to lower it down the drill rod. The bailer performed as desired.

8.3 Field Testing of Drill Rods as a Monitoring Well

On 18 February 1992, field testing was performed at the Textile Town site near the monitoring well containing BTEX (MW-7). The purpose was to see if by removing the septum in the BAT probe whether water could enter the drill rods and be sampled with a 3/4 inch teflon bailer.

The depth to the water table in MW-7 was measured to be 6 feet 1 inch. The well was purged of four well volumes by bailing with a 3 foot long Teflon bailer. The same bailer was then used to fill two 40 mL vials (BAILER1 and BAILER2). The smell of aromatics in the water was present.

The first modified BAT test was performed using a BAT MK2 probe with a HDPE filter and with the septum removed. Tape was placed over the top of the probe to keep it water tight until the desired sampling depth was reached. The probe was pushed to a depth of 11 feet 6 inches (5 feet below the water table). The 3/4 inch bailer was then lowered down the rods to verify that the tape was water tight and that no water had entered the drill rods. No water was recovered. The normal BAT container housing was lowered down the drill rod in order for the needle to puncture the tape and allow water to enter the probe and drill rods. The bailer was then lowered down the drill rod but no water was retrieved. When the probe was retrieved the tape had been punctured severely yet no water had entered the drill rods.

A second test was performed using a BAT MK2 probe with a steel filter which had been pushed to a depth of 11 feet 6 inches. The septum had been removed from this probe and no tape placed over the end. The 3/4 inch bailer again showed that no water had entered the drill rods. At this point, plastic tubing from the vacuum pump was placed down into the drill rods and the top of the rods sealed with tape. The vacuum pump was turned on in hopes of pulling water through the porous filter and into the drill rods. This too was not successful. Joints where drill rods connect may not have been tight. This did not allow a full vacuum to be pulled.

It appears that the pore size of the porous filter inhibits the flow of water into the drill rods. This test did work in the laboratory without the presence of soil (4 feet of water pressure). It is possible that this method would work if the porous filter had a larger pore size.

Conventional BAT sampling then was performed. The BAT MK2 probe with steel filter was pushed to a depth of 11 feet 6 inches at a distance 7 feet 5 inches from MW-7. The probe was purged before sampling. The purge water did smell of aromatics. Two cascaded samplings (BAT1 and BAT3) were performed at this depth. Sampling times were 33 and 31 minutes respectively and yielded lower tubes with no headspace.

The Enviro probe was then pushed 8 feet from MW-7 to a depth of 11 feet 6 inches. The purge water also contained

aromatics. Two cascaded samplings were performed (BAT5 and BAT7). Sampling times were 20 and 13 minutes respectively and yielded tubes with no headspace. Finally, two single tube samplings (BAT9 and BAT10) were performed. Sampling times of 6 and 3 minutes yielded tubes containing around 31 mL (12-14% head space).

Chemical analyses were performed on the GC/MS on 19 February 1992. The results are shown in Table 8.4. The concentrations of benzene recovered in all BAT samples were almost double those found in the bailer samples. The BAT samples obtained with the steel filter yielded the highest concentrations of each of the BTEX components. The BAT samples obtained with a HDPE filter showed slightly lower concentrations of toluene, ethylbenzene and the xylenes than did those obtained with the bailer or the BAT with the steel filter. This could be due to the fact that the HDPE filter sorbs more of these contaminants than does the steel filter.

There were essentially no differences in the concentrations of VOCs recovered between samples from the cascaded no headspace lower tubes (BAT5 and BAT7) and those for the single tubes with 17% headspace (BAT9 and BAT10).

8.4 Summary

The BAT groundwater monitoring system was modified to allow collection of water into an Erlenmeyer flask in order to obtain a larger size sample. The vacuum pump, however, caused

Table 8.4 Chemical Analyses from BAT Testing around MW-7

Sample	Benzene	Toluene	Ethyl- benzene	M,P-Xylene	O-Xylene
BAILER1	95	2	18	11	9
BAILER2	108	2	21	13	10
AVG BAILER	101.5	2	19.5	12	9.5

BAT MK2 probe with Steel filter at 11.5' depth.
No head space.

BAT1	247	13	88	42	91
BAT3	323	14	110	52	109
AVG BAT	285	13.5	99	47	100

Enviro probe with HDPE filter at 11.5' depth.
No head space.

BAT5	210	4	5	4	7
BAT7	176	5	6	5	6
AVG BAT	193	4.5	5.5	4.5	6.5

Single BAT samples taken at 11.5' depth with Enviro probe.
Sample vials contained 17% head space.

BAT9	205	4	5	4	6
BAT10	198	4	7	5	8
AVG BAT	201.5	4	6	4.5	7

All values are in $\mu\text{g}/\text{l}$.

the VOCs to come out of solution. This method may be adequate for other contaminants such as heavy metals.

Results from two tests (Tables 8.1 and 8.4) showed that the BAT probe recovered higher concentrations of VOCs than did the bailer. Testing also showed that the BAT probe with steel filter recovered more VOCs than did the BAT probe with a HDPE filter. BAT samples with and without headspace were compared and showed no significant loss of BTEX in those with headspace. This is in agreement with work done by Pankow (1986).

CHAPTER 9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

In this research an experimental study was made of the BAT groundwater monitoring device, with the major objective of evaluating its effectiveness in sampling VOCs. Both large scale laboratory and field investigations were carried out. At many locations BAT testing was compared to adjacent bailer sampling from monitoring wells. Several modifications to the BAT equipment were attempted in order to improve the sampling process. From the study performed the following conclusions may be drawn.

1. Neither field test procedure, well bailer or BAT system, consistently recovered more VOCs than the other. Concentrations recovered in most cases were comparable. Often variances could be explained by physical differences, e.g. length of BAT porous filter versus length of well screening. Table 9.1 is a summary of the bailer and BAT regarding which sampler recovered higher concentrations of VOCs. Tests where BAT samples were taken at considerable distances (lateral) from the monitoring wells are not included.

2. BAT samples recovered using the stainless steel filter element consistently exhibited higher concentrations of

Table 9.1 Summary Comparison of BAT Versus Bailer Recovery of VOCs

TABLE	BAT VS BAILER
4.4	<
4.5	<
6.3	>
6.4	<
7.3	<
8.1	>
8.4	>

<--REPRESENTS BAILER RECOVERED HIGHER VOCs THAN BAT
 >--REPRESENTS BAT RECOVERED HIGHER VOCs THAN BAILER

VOCs than did samples from probes with the HDPE filter. The latter apparently sorbed significant quantities of the contaminant (Table 8.4 illustrates this fact).

3. Concentrations of VOCs in BAT samples displayed a lower standard deviation and lower relative standard deviation than did samples obtained using the bailer (Tables 4.5 and 7.3). The BAT system exhibited high reproducibility.

4. Use of a "balloon" within the BAT sampling tube to eliminate any possible problems associated with headspace appears promising if a flexible teflon inert balloon of the correct dimensions could be found.

5. Concentrations of VOCs measured in single sample tubes with small amounts of headspace compared favorably with those in test tubes which were obtained by the cascaded method and had no headspace.

6. Large groundwater samples can be drawn from the BAT porous tip using a modification consisting of a vacuum pump, Erlenmeyer flask and tubing tipped with a hypodermic needle which makes contact by piercing the probe's septum. Large samples can be collected in a relatively short time. However, there was significant loss of contaminants as the VOCs were pulled out of solution. The method is also limited, unlike standard BAT testing, to sampling depths of less than 30 feet.

7. Large samples, under certain circumstances, may be recovered from drill rods after the septum (actually in this situation, a piece of tape) has been ruptured. The sample is collected using a small diameter teflon bailer. This method overcomes the two disadvantages listed for the procedure described in conclusion 6.

8. From laboratory and field permeability testing it was found that the BAT underestimates the coefficient of permeability. Values obtained with the BAT system were considerably lower than those obtained from Hazen's equation and from constant and falling head tests.

9. The BAT system is limited in permeability testing to very fine material, specifically silts and clays. This is a consequence of the low permeability of the probe's porous filter which will govern when testing coarse soils.

10. At the sites investigated in this study, all of which consisted primarily of sandy soils, typical sampling times to obtain a sample with no headspace using the cascaded

technique, ranged around 30 minutes. Water pressure heads were between one and five feet.

11. From a limited field study, it would appear that the BAT system would be eminently suitable for determining both the vertical and horizontal variations of contamination, i.e., plume delineation. To avoid cross contamination the BAT Enviro probe should be used and it should be removed and cleaned between sampling depths and soundings.

9.2 Recommendations for Future Testing

A study should be performed on the sorption of different compounds on the different BAT filter materials (HDPE, steel, Teflon). It is important to know exactly how much sorption takes place in these materials when they are used as filters in the BAT groundwater monitoring system. It would also be of importance to determine if pre-saturation of the filters decreases the amount of sorption that takes place and to quantify the amount if any. If the filter is not saturated it may allow the hydrophobic contaminants to come out of the water and to attach (sorb) on to the filter itself. If the filter is presaturated the sorption may be greatly decreased as the contaminants cannot displace the water.

Additional study needs to be made on the concentrations of VOCs recovered in the two sampling tubes in cascaded sampling. In the current study higher concentrations were unexpectedly found in the upper tube which has headspace.

Additional field testing is needed to validate the BAT groundwater monitoring system for pore fluid sampling in the vadose zone. In areas such as the desert southwest the water table can be at great depth. If monitoring wells are installed and screened over the water table, contamination may not be detected in them for decades due to the long period of time for it to migrate to the water table. This can allow a source of contamination to go unnoticed. Sampling the pore fluid above the water table may result in much earlier detection. Monitoring wells do not allow sampling of the pore water in the vadose (unsaturated zone).

Field testing should be performed with the BAT groundwater monitoring system to determine if it could be used to validate the insitu permeability of slurry walls. This would be accomplished by pushing the BAT MK2 probe down inside a completed slurry wall at different depths and running inflow or outflow permeability tests. Quality control guidelines could be developed to determine the number of permeability tests to be performed to validate that a slurry wall has been constructed as prescribed and has met the required minimum permeability.

Testing should be performed, perhaps initially in large scale laboratory samples, to investigate the possibilities of using the BAT system for hydraulic fracture testing. Such testing provides an insitu measurement of the minor principal stress and hence K_0 .

The BAT groundwater monitoring system could be used to take samples at a site in order to validate the accuracy of particular computer models developed for contaminant transport.

9.3 Advantages of the BAT Groundwater Monitoring System

The BAT groundwater monitoring system has several advantages over installation of permanent monitoring wells. Some owners do not want monitoring wells installed because of future financial considerations. These wells at some time will have to be removed or filled with concrete, otherwise the casings can deteriorate and become a pathway for more contamination.

The cost of installation of a shallow monitoring well can be \$5000-\$6000. The cost of using the BAT groundwater monitoring system to obtain water samples is significantly less.

The BAT system obtains water samples that are hermetically sealed so that personnel do not come in contact with the sample which may contain hazardous chemicals. Personnel purging and sampling in monitoring wells may come in contact with the sample, possibly compromising their safety and health.

The BAT probe samples over a very discrete depth while a monitoring well is usually screened over a large interval. Such screening may cause a contaminant to go undetected because it has become diluted.

After installation of a monitoring well, considerable time (usually days to weeks) is required before sampling can begin. This is needed to allow the groundwater to come back to the equilibrium which has been disturbed by the drilling process and the development of the well. With the BAT groundwater monitoring system, water samples can be taken immediately after penetration and purging. With a penetrometer rig several locations can be sampled in the same day.

In sampling a monitoring well, the water surface is exposed to the atmosphere. This may allow VOCs to come out of solution or possibly allow the monitoring well and sample to become contaminated. Since the BAT probe is pushed into the soil, the water that it retrieves is never exposed to the atmosphere.

Considerable time may be required to properly purge a monitoring well. Since it is recommended that four to five well volumes be removed before sampling, a significant time investment may be required especially for deep wells. Little time is required to properly purge the BAT probe (typically 10 minutes or less).

9.4 Disadvantages of the BAT Groundwater Monitoring System

Unless BAT probes are permanently installed, the same point cannot be repeatedly sampled, for comparison purposes, as is done with a permanent monitoring well. Even if the BAT

probe is permanently installed, it samples over a very small interval which can be a problem if placed near the water table and the water table drops. The probe then could be rendered useless by not being able to sample. If the BAT probe is not placed at the proper depth, it may not ever intercept a contamination plume which a monitoring well, screened over a larger interval, would.

The BAT probe like any cone penetrometer cannot be installed in soils with boulders and cobbles or in bedrock. The installation depth with the BAT probe is also limited. It cannot be pushed quite as deep as a standard cone penetrometer since it is slightly larger. Since monitoring wells are installed by drilling they can be placed in basically any type of soil or rock and to significantly greater depths than can the BAT probe.

The BAT probe only retrieves a small sample (35 mL) while sampling from a monitoring well can yield significantly larger samples. Many chemical analyses require samples as large as 1 liter (1000 mL).

If the BAT probe penetrates through a confining layer and is retrieved it could allow possible cross-contamination into the lower aquifer. The BAT needs to be modified to allow the hole to be grouted as it is retrieved to avoid this possibility. The BAT probe should currently only be used in surficial aquifers.

APPENDIX A PERMEABILITY DATA

This appendix contains the computer printouts for all thirty-eight BAT system permeability tests performed. Section A.1 contains five printouts which calculate the permeability just of the needle without any filter. Section A.2 has five printouts of the permeability of the needle and the HDPE filter. Twelve printouts of the permeability of the needle and the steel filter are contained in Section A.3. Five printouts of the permeability of kaolin-sand mixture are contained in Section A.4. Section A.5 contains six printouts of the permeability of the fine mortar sand (yellow/orange sand) and Section A.6 contains 6 printouts of the permeability of the uniform white sand. Section A.7 contains permeability data from Lynch Park. Section A.8 contains the sieve analysis data for the uniform and fine mortar sands. Section A.9 contains constant head permeability test data while Section A.10 contains falling head permeability test data. Section A.11 contains the Atterberg limits of the kaolinite clay. Section A.12 is information on the computer program "Perm" developed by the BAT Envitech Company.

A.1 Needle Permeability Without Filter

```

****      ***      *****
*    *    *    *    *
****      *****    *
*    *    *    *    *
****      *    *    * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-21 TIME: 10:00
TST ID: 1 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .21
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.15
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.66
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 75.81

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-9.15		1	00:00:05	-7.91	2.6x10 ⁻⁵
2	00:00:10	-7.45	3.0x10 ⁻⁵	3	00:00:15	-6.84	3.3x10 ⁻⁵
4	00:00:20	-5.73	3.5x10 ⁻⁵	5	00:00:25	-4.14	3.6x10 ⁻⁵
6	00:00:30	-1.96	4.9x10 ⁻⁵	7	00:00:35	-.34	5.0x10 ⁻⁴
8	00:00:40	-.11					

NUMBER OF DATA POINTS : 8
CALC VOLUME CHANGE (ml): -32.3
ACTUAL VOL CHANGE (ml): 28.0

COMMENTS:

TRIAL #1
PERMEABILITY OF THE NEEDLE WITHOUT ANY FILTER
BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 5.0 x 10⁻⁴ (cm/s) ***

```

*****      ***      *****
*      *      *      *      *
*****      *****      *
*      *      *      *      *
*****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-21 TIME: 10:00
 TST ID: 2 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .21
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -8.71
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.57
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 107.93

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-8.71		1	00:00:05	-8.43	4.1x10 ⁻⁵
2	00:00:10	-8.08	4.8x10 ⁻⁵	3	00:00:15	-7.55	5.5x10 ⁻⁵
4	00:00:20	-6.71	6.6x10 ⁻⁵	5	00:00:25	-5.19	5.9x10 ⁻⁵
6	00:00:30	-2.13	8.2x10 ⁻⁵	7	00:00:35	-.21	8.2x10 ⁻³
8	00:00:40	-.08					

NUMBER OF DATA POINTS : 8
 CALC VOLUME CHANGE (ml): -30.7
 ACTUAL VOL CHANGE (ml): 31.0

COMMENTS:

TRIAL #2
 PERMEABILITY OF NEEDLE WITH NO FILTER
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 8.2×10^{-3} (cm/s) ***

```

*****      ***      *****
*      *      *      *      *
*****      *****      *
*      *      *      *      *
*****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-21 TIME: 10:00
 TST ID: 3 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .21
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -8.45
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.52
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 126.91

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-8.45		1	00:00:05	-8.08	4.2x10 -5
2	00:00:10	-7.67	4.8x10 -5	3	00:00:15	-7.17	6.1x10 -5
4	00:00:20	-6.17	6.6x10 -5	5	00:00:25	-4.27	6.4x10 -5
6	00:00:30	-1.73	9.3x10 -5	7	00:00:35	-.19	2.1x10 -2
8	00:00:40	-.08					

NUMBER OF DATA POINTS : 8
 CALC VOLUME CHANGE (ml): -29.8
 ACTUAL VOL CHANGE (ml): 30.5

COMMENTS:

TRIAL #3
 PERMEABILITY OF NEEDLE WITHOUT ANY FILTER
 BARRY MINES-- UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 2.1×10^{-2} (cm/s) ***

```

*****      ***      *****
*      *      *      *      *
*****      *****      *
*      *      *      *      *
*****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-21 TIME: 10:00
 TST ID: 4 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .21
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.17
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.67
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 74.35

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-9.17		1	00:00:05	-8.99	3.9x10 -5
2	00:00:10	-8.74	4.8x10 -5	3	00:00:15	-8.33	5.7x10 -5
4	00:00:20	-7.65	6.9x10 -5	5	00:00:25	-6.21	5.2x10 -5
6	00:00:30	-2.69	6.2x10 -5	7	00:00:35	-.12	.0x10***
8	00:00:40	-.10					

NUMBER OF DATA POINTS : 8
 CALC VOLUME CHANGE (ml): -32.4
 ACTUAL VOL CHANGE (ml): 33.0

COMMENTS:

TRIAL #4
 PERMEABILITY OF NEEDLE WITHOUT ANY FILTER
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = .0 x 10*** (cm/s) ***

```

*****      ***      *****
*      *      *      *      *
*****      *****      *
*      *      *      *      *
*****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA
TST ID: 5

DATE: 1991-06-21 TIME: 10:00
NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0

FILTER: LENGTH (mm): 40.0

DIAMETER (mm): 40.0

FLOW FACTOR (mm): 285.15

TEST TYPE: VAR HEAD, IN FLOW

CALIBRATION SLOPE : 1.00

INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190

EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .21

INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -7.95

CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.42

INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 163.41

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-7.95		1	00:00:05	-7.56	4.5x10 ⁻⁵
2	00:00:10	-7.07	5.1x10 ⁻⁵	3	00:00:15	-6.39	6.1x10 ⁻⁵
4	00:00:20	-5.36	6.5x10 ⁻⁵	5	00:00:25	-3.59	6.9x10 ⁻⁵
6	00:00:30	-1.61	9.5x10 ⁻⁵	7	00:00:35	-.37	7.2x10 ⁻⁴
8	00:00:40	-.07					

NUMBER OF DATA POINTS : 8

CALC VOLUME CHANGE (ml): -28.0

ACTUAL VOL CHANGE (ml): 28.5

COMMENTS:

TRIAL #5

PERMEABILITY OF NEEDLE WITHOUT ANY FILTER

BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 7.2×10^{-4} (cm/s) ***

A.2 Permeability of Needle and HDPE Filter

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-21 TIME: 09:00
TST ID: 1 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .21
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -8.68
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.57
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 110.12

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-8.68		1	00:00:05	-8.31	4.0x10 ⁻⁵
2	00:00:10	-7.94	4.6x10 ⁻⁵	3	00:00:15	-7.43	4.9x10 ⁻⁵
4	00:00:20	-6.55	5.1x10 ⁻⁵	5	00:00:25	-5.26	5.0x10 ⁻⁵
6	00:00:30	-3.30	5.2x10 ⁻⁵	7	00:00:35	-1.19	1.4x10 ⁻⁴
8	00:00:40	-.23					

NUMBER OF DATA POINTS : 8
CALC VOLUME CHANGE (ml): -30.5
ACTUAL VOL CHANGE (ml): 30.5

COMMENTS:

TRIAL #1
PERMEABILITY OF NEEDLE AND HDPE FILTER
BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 1.4 x 10⁻⁴ (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-21 TIME: 09:00
TST ID: 2 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .21
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -8.85
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.60
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 97.71

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-8.85		1	00:00:05	-8.61	3.7x10 ⁻⁵
2	00:00:10	-8.32	4.5x10 ⁻⁵	3	00:00:15	-7.90	5.0x10 ⁻⁵
4	00:00:20	-7.16	5.3x10 ⁻⁵	5	00:00:25	-6.01	5.5x10 ⁻⁵
6	00:00:30	-4.03	5.2x10 ⁻⁵	7	00:00:35	-1.13	1.6x10 ⁻⁴
8	00:00:40	-.20					

NUMBER OF DATA POINTS : 8
CALC VOLUME CHANGE (ml): -31.2
ACTUAL VOL CHANGE (ml): 31.0

COMMENTS:

TRIAL #2
PERMEABILITY OF NEEDLE AND HDPE FILTER
BARRY MINES-- UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 1.6 x 10⁻⁴ (cm/s) ***


```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-21 TIME: 09:00
 TST ID: 3 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .21
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.06
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.64
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 82.38

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-9.06		1	00:00:05	-8.81	4.0×10^{-5}
2	00:00:10	-8.51	4.3×10^{-5}	3	00:00:15	-8.09	4.6×10^{-5}
4	00:00:20	-7.46	5.2×10^{-5}	5	00:00:25	-6.33	5.1×10^{-5}
6	00:00:30	-4.16	4.7×10^{-5}	7	00:00:35	-1.19	1.4×10^{-4}
8	00:00:40	-.16					

NUMBER OF DATA POINTS : 8
 CALC VOLUME CHANGE (ml): -31.9
 ACTUAL VOL CHANGE (ml): 32.0

COMMENTS:

TRIAL #3
 PERMEABILITY OF NEEDLE AND AND HDPE FILTER
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 1.4×10^{-4} (cm/s) ***

```

*****      ***      *****
*      *      *      *      *
*****      *****      *
*      *      *      *      *
*****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-21 TIME: 09:00
TST ID: 4 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .21
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -8.92
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.62
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 92.60

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
0	00:00:00	-8.92		1	00:00:05	-8.70	4.0x10 ⁻⁵
2	00:00:10	-8.40	4.2x10 ⁻⁵	3	00:00:15	-8.00	5.0x10 ⁻⁵
4	00:00:20	-7.39	5.4x10 ⁻⁵	5	00:00:25	-6.18	5.5x10 ⁻⁵
6	00:00:30	-4.21	5.1x10 ⁻⁵	7	00:00:35	-1.20	1.5x10 ⁻⁴
8	00:00:40	-.20					

NUMBER OF DATA POINTS : 8
CALC VOLUME CHANGE (ml): -31.4
ACTUAL VOL CHANGE (ml): 31.5

COMMENTS:

TRIAL #4
PERMEABILITY OF NEEDLE AND HDPE FILTER
BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 1.5 x 10⁻⁴ (cm/s) ***

```

*****      ***      *****
*      *      *      *      *
*****      *****      *
*      *      *      *      *
*****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-21 TIME: 09:00
TST ID: 5 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .21
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -5.37
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -.91
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 351.75

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-5.37		1	00:00:05	-4.87	6.5×10^{-5}
2	00:00:10	-4.09	5.8×10^{-5}	3	00:00:15	-3.38	5.9×10^{-5}
4	00:00:20	-2.63	6.5×10^{-5}	5	00:00:25	-1.88	7.4×10^{-5}
6	00:00:30	-1.16	8.7×10^{-5}	7	00:00:35	-.68	1.0×10^{-4}
8	00:00:40	-.32	2.4×10^{-4}	9	00:00:45	-.18	

NUMBER OF DATA POINTS : 9
CALC VOLUME CHANGE (ml): -18.7
ACTUAL VOL CHANGE (ml): 18.5

COMMENTS:

TRIAL #5
PERMEABILITY OF NEEDLE AND HDPE FILTER
BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 2.4×10^{-4} (cm/s) ***

A.3 Permeability of Needle and Steel Filter

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-18 TIME: 11:00
TST ID: 1 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .24
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.16
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.64
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 75.08

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-9.16		1	00:00:05	-8.92	3.6×10^{-5}
2	00:00:10	-8.67	4.2×10^{-5}	3	00:00:15	-8.27	4.9×10^{-5}
4	00:00:20	-7.68	5.3×10^{-5}	5	00:00:25	-6.48	4.9×10^{-5}
6	00:00:30	-4.34	4.2×10^{-5}	7	00:00:35	-1.39	6.0×10^{-5}
8	00:00:40	-.32	6.5×10^{-5}	9	00:00:45	-.24	9.6×10^{-5}
10	00:00:50	-.21					

NUMBER OF DATA POINTS : 10
CALC VOLUME CHANGE (ml): -32.3
ACTUAL VOL CHANGE (ml): 32.0

COMMENTS:

TRIAL #1
PERMEABILITY OF NEEDLE AND STEEL FILTER
BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 9.6×10^{-5} (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-18 TIME: 11:00
 TST ID: 2 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .23
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.10
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.64
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 79.46

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-9.10		1	00:00:05	-8.92	2.7×10^{-5}
2	00:00:10	-8.75	4.5×10^{-5}	3	00:00:15	-8.32	4.8×10^{-5}
4	00:00:20	-7.77	5.7×10^{-5}	5	00:00:25	-6.83	5.6×10^{-5}
6	00:00:30	-4.60	4.7×10^{-5}	7	00:00:35	-1.44	7.1×10^{-5}
8	00:00:40	-.23	1.7×10^{-4}	9	00:00:45	-.16	4.6×10^{-4}
10	00:00:50	-.14					

NUMBER OF DATA POINTS : 10
 CALC VOLUME CHANGE (ml): -32.1
 ACTUAL VOL CHANGE (ml): 32.5

COMMENTS:

TRIAL #2
 PERMEABILITY OF NEEDLE AND STEEL FILTER
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 4.6×10^{-4} (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-18 TIME: 11:00
 TST ID: 3 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .24
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.05
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.62
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 83.11

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-9.05		1	00:00:05	-8.81	2.1x10 ⁻⁵
2	00:00:10	-8.67	3.8x10 ⁻⁵	3	00:00:15	-8.31	4.9x10 ⁻⁵
4	00:00:20	-7.81	5.5x10 ⁻⁵	5	00:00:25	-6.79	6.0x10 ⁻⁵
6	00:00:30	-4.91	4.9x10 ⁻⁵	7	00:00:35	-1.41	8.4x10 ⁻⁵
8	00:00:40	-.16	4.1x10 ⁻³	9	00:00:45	-.09	

NUMBER OF DATA POINTS : 9
 CALC VOLUME CHANGE (ml): -31.9
 ACTUAL VOL CHANGE (ml): 33.5

COMMENTS:

TRIAL #3
 PERMEABILITY OF NEEDLE AND STEEL FILTER
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 4.1 x 10⁻³ (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-21 TIME: 11:00
 TST ID: 4 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .24
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.23
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.65
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 69.97

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-9.23		1	00:00:05	-9.09	2.2x10 ⁻⁵
2	00:00:10	-8.97	4.1x10 ⁻⁵	3	00:00:15	-8.64	5.1x10 ⁻⁵
4	00:00:20	-8.20	5.8x10 ⁻⁵	5	00:00:25	-7.28	6.4x10 ⁻⁵
6	00:00:30	-5.39	4.5x10 ⁻⁵	7	00:00:35	-1.30	8.4x10 ⁻⁵
8	00:00:40	-.16	2.4x10 ⁻³	9	00:00:45	-.11	

NUMBER OF DATA POINTS : 9
 CALC VOLUME CHANGE (ml): -32.6
 ACTUAL VOL CHANGE (ml): 32.5

COMMENTS:

TRIAL #4
 PERMEABILITY OF NEEDLE AND STEEL FILTER
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 2.4 x 10⁻³ (cm/s) ***

```

*****      ***      *****
*      *      *      *      *
*****      *****      *
*      *      *      *      *
*****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-18 TIME: 11:30
TST ID: 5 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .24
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.09
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.63
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 80.19

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-9.09		1	00:00:05	-8.91	2.6×10^{-5}
2	00:00:10	-8.75	4.1×10^{-5}	3	00:00:15	-8.37	4.9×10^{-5}
4	00:00:20	-7.88	5.4×10^{-5}	5	00:00:25	-6.89	5.8×10^{-5}
6	00:00:30	-5.11	4.7×10^{-5}	7	00:00:35	-1.68	7.0×10^{-5}
8	00:00:40	-.24	6.2×10^{-4}	9	00:00:45	-.15	

NUMBER OF DATA POINTS : 9
CALC VOLUME CHANGE (ml): -32.1
ACTUAL VOL CHANGE (ml): 33.0

COMMENTS:

TRIAL #5
PERMEABILITY OF NEEDLE AND STEEL FILTER
BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 6.2×10^{-4} (cm/s) ***


```

*****      ***      *****
*      *      *      *      *
*****      *****      *
*      *      *      *      *
*****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-18 TIME: 11:30
 TST ID: 6 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .24
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.38
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.68
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 59.02

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
0	00:00:00	-9.38		1	00:00:05	-9.22	3.2x10 ⁻⁵
2	00:00:10	-9.05	3.3x10 ⁻⁵	3	00:00:15	-8.90	4.6x10 ⁻⁵
4	00:00:20	-8.52	5.8x10 ⁻⁵	5	00:00:25	-7.75	7.0x10 ⁻⁵
6	00:00:30	-6.08	4.2x10 ⁻⁵	7	00:00:35	-1.42	1.1x10 ⁻⁴
8	00:00:40	-.19					

NUMBER OF DATA POINTS : 8
 CALC VOLUME CHANGE (ml): -33.1
 ACTUAL VOL CHANGE (ml): 34.5

COMMENTS:

TRIAL #6
 PERMEABILITY OF NEEDLE AND STEEL FILTER
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 1.1 x 10⁻⁴ (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-18 TIME: 12:00
 TST ID: 7 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .24
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.35
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.68
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 61.21

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
0	00:00:00	-9.35		1	00:00:05	-9.16	2.7x10 ⁻⁵
2	00:00:10	-9.01	3.7x10 ⁻⁵	3	00:00:15	-8.75	4.0x10 ⁻⁵
4	00:00:20	-8.32	4.9x10 ⁻⁵	5	00:00:25	-7.70	5.9x10 ⁻⁵
6	00:00:30	-6.18	4.3x10 ⁻⁵	7	00:00:35	-2.65	5.0x10 ⁻⁵
8	00:00:40	-.17	1.1x10 ⁻³	9	00:00:45	-.16	

NUMBER OF DATA POINTS : 9
 CALC VOLUME CHANGE (ml): -33.0
 ACTUAL VOL CHANGE (ml): 34.0

COMMENTS:

TRIAL #7
 PERMEABILITY OF NEEDLE AND STEEL FILTER
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 1.1 x 10⁻³ (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-18 TIME: 12:00
 TST ID: 8 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .24
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.29
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.67
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 65.59

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
0	00:00:00	-9.29		1	00:00:05	-9.12	3.6x10 ⁻⁵
2	00:00:10	-8.91	4.0x10 ⁻⁵	3	00:00:15	-8.65	4.5x10 ⁻⁵
4	00:00:20	-8.16	5.2x10 ⁻⁵	5	00:00:25	-7.34	6.0x10 ⁻⁵
6	00:00:30	-5.58	4.3x10 ⁻⁵	7	00:00:35	-1.61	9.6x10 ⁻⁵
8	00:00:40	-.20					

NUMBER OF DATA POINTS : 8
 CALC VOLUME CHANGE (ml): -32.8
 ACTUAL VOL CHANGE (ml): 33.5

COMMENTS:

TRIAL #8
 PERMEABILITY OF NEEDLE AND STEEL FILTER
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 9.6 x 10⁻⁵ (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-18 TIME: 12:30
 TST ID: 9 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .24
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.22
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.65
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 70.70

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
0	00:00:00	-9.22		1	00:00:05	-9.08	3.2x10 ⁻⁵
2	00:00:10	-8.90	3.9x10 ⁻⁵	3	00:00:15	-8.60	4.7x10 ⁻⁵
4	00:00:20	-8.18	5.9x10 ⁻⁵	5	00:00:25	-7.30	5.8x10 ⁻⁵
6	00:00:30	-5.33	4.4x10 ⁻⁵	7	00:00:35	-2.00	8.3x10 ⁻⁵
8	00:00:40	-.20					

NUMBER OF DATA POINTS : 8
 CALC VOLUME CHANGE (ml): -32.5
 ACTUAL VOL CHANGE (ml): 33.5

COMMENTS:

TRIAL #9
 PERMEABILITY OF NEEDLE AND STEEL FILTER
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 8.3×10^{-5} (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-18 TIME: 12:30
TST ID: 10 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .24
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.42
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.69
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 56.10

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
0	00:00:00	-9.42		1	00:00:05	-9.29	2.5x10 -5
2	00:00:10	-9.17	3.6x10 -5	3	00:00:15	-8.94	4.7x10 -5
4	00:00:20	-8.60	4.7x10 -5	5	00:00:25	-7.85	7.6x10 -5
6	00:00:30	-6.77	4.3x10 -5	7	00:00:35	-1.80	8.5x10 -5
8	00:00:40	-.20					

NUMBER OF DATA POINTS : 8
CALC VOLUME CHANGE (ml): -33.2
ACTUAL VOL CHANGE (ml): 34.0

COMMENTS:

TRIAL #10
PERMEABILITY OF NEEDLE AND STEEL FILTER
BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 8.5×10^{-5} (cm/s) ***

```

*****   ***   *****
*       *   *       *
*****   *****   *
*       *   *       *
*****   *       *   * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-18 TIME: 12:30
 TST ID: 11 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .24
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -7.63
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.33
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 186.77

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
0	00:00:00	-7.63		1	00:00:05	-7.23	4.0x10 ⁻⁵
2	00:00:10	-6.78	4.5x10 ⁻⁵	3	00:00:15	-6.20	4.8x10 ⁻⁵
4	00:00:20	-5.33	5.2x10 ⁻⁵	5	00:00:25	-4.31	5.4x10 ⁻⁵
6	00:00:30	-2.88	5.8x10 ⁻⁵	7	00:00:35	-1.63	9.0x10 ⁻⁵
8	00:00:40	-.74					

NUMBER OF DATA POINTS : 8
 CALC VOLUME CHANGE (ml): -26.2
 ACTUAL VOL CHANGE (ml): 27.0

COMMENTS:

TRIAL #11
 PERMEABILITY OF NEEDLE AND STEEL FILTER
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 9.0 x 10⁻⁵ (cm/s) ***

```

*****      ***      *****
*      *      *      *      *
*****      *****      *
*      *      *      *      *
*****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1991-06-18 TIME: 12:30
 TST ID: 12 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .24
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -7.35
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.28
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 207.21

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
0	00:00:00	-7.35		1	00:00:05	-6.91	4.1x10 ⁻⁵
2	00:00:10	-6.43	4.4x10 ⁻⁵	3	00:00:15	-5.82	4.7x10 ⁻⁵
4	00:00:20	-5.03	5.1x10 ⁻⁵	5	00:00:25	-4.05	5.3x10 ⁻⁵
6	00:00:30	-2.79	5.7x10 ⁻⁵	7	00:00:35	-1.70	6.2x10 ⁻⁵
8	00:00:40	-.87	7.4x10 ⁻⁵	9	00:00:45	-.38	7.8x10 ⁻⁵
10	00:00:50	-.21	4.8x10 ⁻⁵	11	00:00:55	-.19	7.2x10 ⁻⁵
12	00:01:00	-.13					

NUMBER OF DATA POINTS : 12
 CALC VOLUME CHANGE (ml): -25.8
 ACTUAL VOL CHANGE (ml): 26.5

COMMENTS:

TRIAL #12
 PERMEABILITY OF NEEDLE AND STEEL FILTER
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 7.2 x 10⁻⁵ (cm/s) ***

A.4 Permeability of Kaolin-Sand Mixture

```

****      ***      *****
*   *   *   *   *
****      *****   *
*   *   *   *   *
****      *   *   * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-09 TIME: 08:00
TST ID: 1 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0

FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .23
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -8.84
CONTAINER X-AREA (cm²): 1.96 80% RECOVERY PRESS (m) : -1.58
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 98.44

NO	TIME hh:mm:ss	PRESS m H ₂ O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H ₂ O	PERMEAB cm/s
0	00:00:00	-8.84		1	00:00:05	-8.13	1.9x10 ⁻⁶
2	00:00:30	-8.03	1.0x10 ⁻⁶	3	00:01:00	-7.96	7.7x10 ⁻⁷
4	00:02:00	-7.85	6.4x10 ⁻⁷	5	00:05:00	-7.52	4.8x10 ⁻⁷
6	00:12:00	-6.77	3.8x10 ⁻⁷	7	00:15:00	-6.44	3.3x10 ⁻⁷
8	00:20:00	-5.88	2.8x10 ⁻⁷	9	00:25:00	-5.35	

NUMBER OF DATA POINTS : 9
CALC VOLUME CHANGE (ml): -25.6
ACTUAL VOL CHANGE (ml): 12.0

COMMENTS:

TRIAL 1
50% CLAY -- 50% SAND
BARRY MINES
UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 2.8×10^{-7} (cm/s) ***


```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-09 TIME: 08:30
 TST ID: 2 NAME: BARRY MINES
 FILTER DEPTH (m or ft) : 0

FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE: 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m): .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m): .23
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m): -8.81
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m): -1.58
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m): 100.63

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-8.81		1	00:00:05	-8.42	9.9x10 ⁻⁷
2	00:00:30	-8.38	1.3x10 ⁻⁶	3	00:01:00	-8.30	9.8x10 ⁻⁷
4	00:02:00	-8.18	7.8x10 ⁻⁷	5	00:05:00	-7.88	6.3x10 ⁻⁷
6	00:08:00	-7.58	4.8x10 ⁻⁷	7	00:15:00	-6.87	3.6x10 ⁻⁷
8	00:20:00	-6.35	3.1x10 ⁻⁷	9	00:25:00	-5.86	2.6x10 ⁻⁷
10	00:30:00	-5.33	2.1x10 ⁻⁷	11	00:50:00	-3.39	

NUMBER OF DATA POINTS : 11
 CALC VOLUME CHANGE (ml): -28.5
 ACTUAL VOL CHANGE (ml): 12.5

COMMENTS:

TRIAL 2
 50% CLAY -- 50% SAND
 BaRRY MINES
 UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 2.1 x 10⁻⁷ (cm/s) ***

```

*****      ***      *****
*      *      *      *      *
*****      *****      *
*      *      *      *      *
*****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-09 TIME: 09:30
 TST ID: 3 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm) 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m): .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m): .23
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m): -8.85
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m): -1.59
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m): 97.71

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-8.85		1	00:00:05	-8.61	2.0x10 -6
2	00:00:30	-8.54	1.1x10 -6	3	00:01:00	-8.49	1.1x10 -6
4	00:02:00	-8.41	9.6x10 -7	5	00:03:00	-8.28	9.1x10 -7
6	00:04:00	-8.20	8.3x10 -7	7	00:05:00	-8.09	2.9x10 -7
8	00:45:00	-4.00	2.0x10 -7	9	00:50:00	-3.54	

NUMBER OF DATA POINTS : 9
 CALC VOLUME CHANGE (ml): -28.5
 ACTUAL VOL CHANGE (ml): 12.5

COMMENTS:

TRIAL 3
 50% CLAY -- 50% SAND
 BARRY MINES
 UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 2.0×10^{-7} (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-09 TIME: 10:00
TST ID: 4 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0

FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m): .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m): .23
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m): -9.07
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m): -1.63
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m): 81.65

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-9.07		1	00:00:05	-8.85	3.4x10 ⁻⁶
2	00:00:30	-8.74	1.4x10 ⁻⁶	3	00:01:00	-8.67	8.9x10 ⁻⁷
4	00:02:00	-8.60	7.8x10 ⁻⁷	5	00:05:00	-8.36	5.8x10 ⁻⁷
6	00:11:00	-7.84	4.4x10 ⁻⁷	7	00:17:00	-7.30	3.0x10 ⁻⁷
8	00:29:30	-6.07	2.0x10 ⁻⁷	9	00:45:00	-4.52	

NUMBER OF DATA POINTS : 9
CALC VOLUME CHANGE (ml): -28.6
ACTUAL VOL CHANGE (ml): 12.5

COMMENTS:

TRIAL 4
50% CLAY -- 50% SAND
BARRY MINES
UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 2.0 x 10⁻⁷ (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-09 TIME: 11:00
 TST ID: 5 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.1 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m): .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m): .23
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m): -9.14
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m): -1.64
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m): 76.54

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-9.14		1	00:00:05	-8.87	2.7×10^{-6}
2	00:00:30	-8.78	1.9×10^{-6}	3	00:01:00	-8.69	1.5×10^{-6}
4	00:02:00	-8.55	1.0×10^{-6}	5	00:06:30	-7.86	5.7×10^{-7}
6	00:12:30	-6.96	2.7×10^{-7}	7	00:30:00	-4.57	1.9×10^{-7}
8	00:48:00	-2.66	2.0×10^{-7}	9	00:52:00	-2.33	

NUMBER OF DATA POINTS : 9
 CALC VOLUME CHANGE (ml): -31.1
 ACTUAL VOL CHANGE (ml): 10.0

COMMENTS:

TRIAL 5
 50% CLAY -- 50% SAND
 BARRY MINES
 UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 2.0×10^{-7} (cm/s) ***

A.5 Permeability of Yellow Fine Mortar Sand

```

****      ***      *****
*   *   *   *   *
****      *****   *
*   *   *   *   *
****      *   *   * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-05 TIME: 09:00
TST ID: 1 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m): .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m): .22
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m): -8.00
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m): -1.42
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m): 159.76

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-8.00		1	00:00:05	-7.59	4.6x10 ⁻⁵
2	00:00:10	-7.08	5.2x10 ⁻⁵	3	00:00:15	-6.34	5.9x10 ⁻⁵
4	00:00:20	-5.28	6.0x10 ⁻⁵	5	00:00:25	-3.56	6.3x10 ⁻⁵
6	00:00:30	-1.79	7.7x10 ⁻⁵	7	00:00:35	-.52	1.2x10 ⁻⁴
8	00:00:40	-.21	4.2x10 ⁻⁴	9	00:00:45	-.16	

NUMBER OF DATA POINTS : 9
CALC VOLUME CHANGE (ml): -28.1
ACTUAL VOL CHANGE (ml): 28.5

COMMENTS:
YELLOW SAND
TRIAL 1
BARRY MINES
UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 4.2×10^{-4} (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-05 TIME: 09:10
TST ID: 2 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m): .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m): .22
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m): -8.97
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m): -1.62
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m): 88.95

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-8.97		1	00:00:05	-8.72	4.2x10 -5
2	00:00:10	-8.40	5.2x10 -5	3	00:00:15	-7.84	5.7x10 -5
4	00:00:20	-6.96	6.4x10 -5	5	00:00:25	-5.26	5.2x10 -5
6	00:00:30	-1.87	7.3x10 -5	7	00:00:35	-.28	6.5x10 -4
8	00:00:40	-.16					

NUMBER OF DATA POINTS : 8
CALC VOLUME CHANGE (ml): -31.6
ACTUAL VOL CHANGE (ml): 32.0

COMMENTS:

YELLOW SAND
TRIAL 2
BARRY MINES
UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 6.5×10^{-4} (cm/s) ***

```

****      ***      *****
*    *    *    *    *
****      *****      *
*    *    *    *    *
****      *    *    * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-05 TIME: 09:20
 TST ID: 3 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m): .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m): .22
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m): -9.13
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m): -1.65
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m): 77.27

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-9.13		1	00:00:05	-8.95	4.6x10 -5
2	00:00:10	-8.64	4.9x10 -5	3	00:00:15	-8.13	5.6x10 -5
4	00:00:20	-7.45	6.3x10 -5	5	00:00:25	-5.86	5.0x10 -5
6	00:00:30	-2.56	5.9x10 -5	7	00:00:35	-.22	1.1x10 -3
8	00:00:40	-.15					

NUMBER OF DATA POINTS : 8
 CALC VOLUME CHANGE (ml): -32.2
 ACTUAL VOL CHANGE (ml): 32.5

COMMENTS:
 YELLOW SAND
 TRIAL 3
 BARRY MINES
 UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 1.1×10^{-3} (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-05 TIME: 09:30
 TST ID: 4 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .22
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -8.99
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.62
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 87.49

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-8.99		1	00:00:05	-8.77	4.0×10^{-5}
2	00:00:10	-8.48	5.6×10^{-5}	3	00:00:15	-7.94	5.6×10^{-5}
4	00:00:20	-6.96	6.0×10^{-5}	5	00:00:25	-5.48	5.1×10^{-5}
6	00:00:30	-2.40	6.4×10^{-5}	7	00:00:35	-.24	9.6×10^{-4}
8	00:00:40	-.15					

NUMBER OF DATA POINTS : 8
 CALC VOLUME CHANGE (ml): -31.7
 ACTUAL VOL CHANGE (ml): 32.0

COMMENTS:

TRIAL 4
 YELLOW SAND
 BARRY MINES
 UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 9.6×10^{-4} (cm/s) ***


```

****      ***      *****
*   *   *   *   *
****      *****      *
*   *   *   *   *
****      *   *   * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-05 TIME: 09:40
TST ID: 5 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 72.0 LIQUID START LEVEL (m) : .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .22
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -7.89
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.40
INITIAL GAS VOL (ml): 72.3 MAX FINAL PRESSURE (m) : 342.49

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-7.89		1	00:00:05	-7.56	4.6x10 -5
2	00:00:10	-7.33	5.0x10 -5	3	00:00:15	-7.05	5.3x10 -5
4	00:00:20	-6.70	5.4x10 -5	5	00:00:25	-6.28	5.1x10 -5
6	00:00:30	-5.81	4.0x10 -5	7	00:00:35	-5.35	2.9x10 -5
8	00:00:40	-5.10	2.2x10 -5	9	00:00:45	-4.86	2.3x10 -5
10	00:00:50	-4.60	2.7x10 -5	11	00:00:55	-4.30	2.5x10 -5
12	00:01:00	-3.90	2.3x10 -5	13	00:01:05	-3.70	2.3x10 -5
14	00:01:10	-3.40	2.1x10 -5	15	00:01:30	-2.25	2.2x10 -5
16	00:02:00	-.93	5.3x10 -5	17	00:02:30	-.49	

NUMBER OF DATA POINTS : 17
CALC VOLUME CHANGE (ml): -54.4
ACTUAL VOL CHANGE (ml): 54.5

COMMENTS:

YELLOW SAND
TRIAL 5 USING CASCADEDED TECHNIQUE
BARRY MINES
UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 5.3×10^{-5} (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-05 TIME: 09:50
TST ID: 6 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 72.0 LIQUID START LEVEL (m) : .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .22
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -8.03
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.43
INITIAL GAS VOL (ml): 72.5 MAX FINAL PRESSURE (m) : 323.17

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-8.03		1	00:00:05	-7.82	5.5x10 -5
2	00:00:10	-7.57	5.9x10 -5	3	00:00:20	-7.00	4.4x10 -5
4	00:00:30	-6.11	3.0x10 -5	5	00:00:40	-5.58	2.0x10 -5
6	00:00:50	-5.19	1.7x10 -5	7	00:01:00	-4.79	1.8x10 -5
8	00:01:10	-4.35	1.8x10 -5	9	00:01:30	-3.42	1.6x10 -5
10	00:02:00	-1.98	2.6x10 -5	11	00:02:45	-.66	

NUMBER OF DATA POINTS : 11
CALC VOLUME CHANGE (ml): -55.3
ACTUAL VOL CHANGE (ml): 55.0

COMMENTS:
YELLOW SAND
TRIAL 6 USING CASCADED TECHNIQUE
BARRY MINES
UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 2.6×10^{-5} (cm/s) ***

A.6 Permeability of a Uniform Sand

```

****      ***      *****
*    *    *    *    *
****      *****    *
*    *    *    *    *
****      *    *    * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-05 TIME: 08:00
TST ID: 1 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .20
INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -4.83
CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -.81
INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 391.17

NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s	NO	TIME hh:mm:ss	PRESS m H2O	PERMEAB cm/s
0	00:00:00	-4.83		1	00:00:05	-4.10	5.8x10 ⁻⁵
2	00:00:10	-3.43	6.1x10 ⁻⁵	3	00:00:15	-2.75	6.3x10 ⁻⁵
4	00:00:20	-2.01	6.8x10 ⁻⁵	5	00:00:25	-1.47	6.6x10 ⁻⁵
6	00:00:30	-.92	6.2x10 ⁻⁵	7	00:00:35	-.72	4.1x10 ⁻⁵
8	00:00:40	-.54	3.2x10 ⁻⁵	9	00:00:45	-.47	1.6x10 ⁻⁵
10	00:00:50	-.43	1.8x10 ⁻⁵	11	00:00:55	-.41	

NUMBER OF DATA POINTS : 11
CALC VOLUME CHANGE (ml): -16.3
ACTUAL VOL CHANGE (ml): 16.0

COMMENTS:
WHITE QUARTZ SAND
TRIAL 1
BARRY MINES
UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 1.8 x 10⁻⁵ (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-05 TIME: 08:10
 TST ID: 2 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .20
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -3.70
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -.58
 INITIAL GAS VOL (ml): 36.3 MAX FINAL PRESSURE (m) : 471.14

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-3.70		1	00:00:05	-2.84	5.7x10 -5
2	00:00:10	-2.32	5.6x10 -5	3	00:00:15	-1.85	5.7x10 -5
4	00:00:20	-1.45	5.6x10 -5	5	00:00:25	-1.08	5.5x10 -5
6	00:00:30	-.86	4.6x10 -5	7	00:00:35	-.65	3.9x10 -5
8	00:00:40	-.56	2.5x10 -5	9	00:00:45	-.48	1.9x10 -5
10	00:00:50	-.45	2.0x10 -5	11	00:00:55	-.42	

NUMBER OF DATA POINTS : 11
 CALC VOLUME CHANGE (ml): -12.0
 ACTUAL VOL CHANGE (ml): 11.8

COMMENTS:

WHITE QUARTZ SAND
 TRIAL 2
 BARRY MINES
 UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 2.0×10^{-5} (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-05 TIME: 08:15
 TST ID: 3 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .20
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -4.00
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -.64
 INITIAL GAS VOL (ml): 36.3 MAX FINAL PRESSURE (m) : 449.35

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-4.00		1	00:00:05	-3.28	5.7x10 -5
2	00:00:10	-2.71	5.8x10 -5	3	00:00:15	-2.19	5.8x10 -5
4	00:00:20	-1.66	5.8x10 -5	5	00:00:25	-1.28	5.4x10 -5
6	00:00:30	-.98	4.9x10 -5	7	00:00:35	-.74	4.1x10 -5
8	00:00:40	-.62	2.7x10 -5	9	00:00:45	-.53	1.9x10 -5
10	00:00:50	-.49	1.2x10 -5	11	00:00:55	-.46	1.3x10 -5
12	00:01:00	-.44					

NUMBER OF DATA POINTS : 12
 CALC VOLUME CHANGE (ml): -13.1
 ACTUAL VOL CHANGE (ml): 12.7

COMMENTS:

WHITE QUARTZ SAND
 TRIAL 3
 BARRY MINES
 UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 1.3×10^{-5} (cm/s) ***

```

****      ***      *****
*    *    *    *    *
****      *****    *
*    *    *    *    *
****      *    *    * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-05 TIME: 08:20
 TST ID: 4 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .20
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -8.66
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.57
 INITIAL GAS VOL (ml): 36.3 MAX FINAL PRESSURE (m) : 110.95

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-8.66		1	00:00:05	-8.30	4.2x10 ⁻⁵
2	00:00:10	-7.91	4.7x10 ⁻⁵	3	00:00:15	-7.34	5.0x10 ⁻⁵
4	00:00:20	-6.46	5.5x10 ⁻⁵	5	00:00:25	-5.04	5.1x10 ⁻⁵
6	00:00:30	-2.69	5.2x10 ⁻⁵	7	00:00:35	-1.05	4.8x10 ⁻⁵
8	00:00:40	-.58	7.4x10 ⁻⁵	9	00:00:45	-.54	

NUMBER OF DATA POINTS : 9
 CALC VOLUME CHANGE (ml): -30.1
 ACTUAL VOL CHANGE (ml): 30.5

COMMENTS:
 WHITE QUARTZ SAND
 TRIAL 4
 BARRY MINES
 UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 7.4×10^{-5} (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-05 TIME: 08:30
 TST ID: 5 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .20
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.23
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.69
 INITIAL GAS VOL (ml): 36.3 MAX FINAL PRESSURE (m) : 69.55

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-9.23		1	00:00:05	-8.96	3.7x10 ⁻⁵
2	00:00:10	-8.70	4.4x10 ⁻⁵	3	00:00:15	-8.30	5.6x10 ⁻⁵
4	00:00:20	-7.60	5.9x10 ⁻⁵	5	00:00:25	-5.98	4.5x10 ⁻⁵
6	00:00:30	-2.99	4.3x10 ⁻⁵	7	00:00:35	-.67	4.7x10 ⁻⁵
8	00:00:40	-.57	5.3x10 ⁻⁵	9	00:00:45	-.56	

NUMBER OF DATA POINTS : 9
 CALC VOLUME CHANGE (ml): -32.2
 ACTUAL VOL CHANGE (ml): 32.0

COMMENTS:
 WHITE QUARTZ SAND
 TRIAL 5
 BARRY MINES
 UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 5.3 x 10⁻⁵ (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: GAINESVILLE, FLORIDA DATE: 1992-03-05 TIME: 08:35
 TST ID: 6 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 0
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .20
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.09
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.66
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 80.19

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-9.09		1	00:00:05	-8.75	3.5x10 ⁻⁵
2	00:00:10	-8.47	4.6x10 ⁻⁵	3	00:00:15	-7.97	5.4x10 ⁻⁵
4	00:00:20	-7.18	5.5x10 ⁻⁵	5	00:00:25	-5.50	4.5x10 ⁻⁵
6	00:00:30	-2.82	4.4x10 ⁻⁵	7	00:00:35	-.84	4.4x10 ⁻⁵
8	00:00:40	-.57	5.8x10 ⁻⁵	9	00:00:45	-.55	

NUMBER OF DATA POINTS : 9
 CALC VOLUME CHANGE (ml): -31.9
 ACTUAL VOL CHANGE (ml): 32.0

COMMENTS:
 WHITE QUARTZ SAND
 TRIAL 6
 BARRY MINES
 UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 5.8 x 10⁻⁵ (cm/s) ***

A.7 Permeability Data from Lynch Park

```

****      ***      *****
*    *    *    *    *
****      *****    *
*    *    *    *    *
****      *    *    * R

```

IN SITU PERMEABILITY TEST

SITE: Lynch Park, Gainesville DATE: 1992-03-19 TIME: 13:20
 TST ID: Group 1 NAME: Barry Mines

FILTER DEPTH (m or ft) : 11 ft
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .68
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.02
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.26
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 85.30

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-9.02		1	00:00:05	-8.50	9.7x10 ⁻⁷
2	00:01:00	-8.40	6.9x10 ⁻⁷	3	00:03:00	-8.24	7.7x10 ⁻⁷
4	00:05:00	-8.06	8.7x10 ⁻⁷	5	00:10:00	-7.41	4.7x10 ⁻⁷
6	00:23:00	-4.91	3.2x10 ⁻⁷	7	00:32:00	-2.99	3.1x10 ⁻⁷
8	00:33:00	-2.80					

NUMBER OF DATA POINTS : 8
 CALC VOLUME CHANGE (ml): -30.2
 ACTUAL VOL CHANGE (ml): 27.0

COMMENTS:

Group 1 results

*** FINAL CALCULATED PERMEABILITY = 3.1 x 10⁻⁷ (cm/s) ***

```

****      ***      *****
*      *      *      *      *
****      *****      *
*      *      *      *      *
****      *      *      * R

```

IN SITU PERMEABILITY TEST

SITE: LYNCH PARK, GAINESVILLE DATE: 1992-03-19 TIME: 14:00
 TST ID: 2 NAME: BARRY MINES

FILTER DEPTH (m or ft) : 11 FT
 FILTER: LENGTH (mm): 40.0 TEST TYPE: VAR HEAD, IN FLOW
 DIAMETER (mm): 40.0 CALIBRATION SLOPE : 1.00
 FLOW FACTOR (mm): 285.15 INTERCEPT : .00

TEST CONTAINER VOL (ml): 36.0 LIQUID START LEVEL (m) : .190
 EXT CYLINDER VOL (ml): .5 STATIC PORE PRESS (m) : .63
 INITIAL LIQUID VOL (ml): .0 INITIAL TEST PRESS (m) : -9.45
 CONTAINER X-AREA (cm2): 1.96 80% RECOVERY PRESS (m) : -1.39
 INITIAL GAS VOL (ml): 36.5 MAX FINAL PRESSURE (m) : 53.91

NO	TIME	PRESS	PERMEAB	NO	TIME	PRESS	PERMEAB
	hh:mm:ss	m H2O	cm/s		hh:mm:ss	m H2O	cm/s
==	=====	=====	=====	==	=====	=====	=====
0	00:00:00	-9.45		1	00:00:05	-8.97	9.0x10 -7
2	00:03:00	-8.68	7.3x10 -7	3	00:05:00	-8.50	6.2x10 -7
4	00:10:00	-7.93	4.7x10 -7	5	00:15:00	-7.17	3.9x10 -7
6	00:20:00	-6.20	3.2x10 -7	7	00:25:00	-5.03	2.7x10 -7
8	00:27:00	-4.53					

NUMBER OF DATA POINTS : 8
 CALC VOLUME CHANGE (ml): -31.0
 ACTUAL VOL CHANGE (ml): 23.0

COMMENTS:

LYNCH PARK--LEAKING UNDEGROUND STORAGE TANK SITE
 GROUNDWATER SAMPLING FOR BTEX
 INSITU LAB CLASS
 BARRY MINES--UNIVERSITY OF FLORIDA

*** FINAL CALCULATED PERMEABILITY = 2.7×10^{-7} (cm/s) ***

A.8 Sieve Analysis Data

Sieve #	Opening Size (mm)	Percent Passing	
		Uniform Sand White (EPK)	Fine Mortar Sand (Yellow)
4.0	4.75	100.0	100.0
8.0	2.36	100.0	100.0
10.0	2.00	100.0	100.0
16.0	1.19	100.0	100.0
20.0	0.838	100.0	99.0
30.0	0.60	99.0	97.7
40.0	0.425	94.6	87.9
50.0	0.297	64.9	36.5
60.0	0.250	61.0	32.2
100.0	0.149	3.4	3.7
120.0	0.125	2.4	2.8
140.0	0.105	0.5	1.4
200.0	0.075	0.0	0.0
% Coarse Sand		0	0
% Medium Sand		5.4	12.1
% Fine Sand		94.6	87.9
% Silt		0	0
D60		.27 mm	.33 mm
D30		.20 mm	.26 mm
D10		.18 mm	.19 mm
Cu		1.5	1.74
Cz		0.82	1.08

$$C_u = \frac{D_{60}}{D_{10}}$$

$$C_z = \frac{D_{30}^2}{D_{10} \times D_{60}}$$

EPK Information on Sand

SiO₂--99.3 % minimumFe₂O₃--0.045% maximumAl₂O₃--0.50%+-0.15

CaO--0.001%+-0.005

TiO₂--0.03% maximumNa₂O--0.01% maximum

A.9 Constant Head Permeability Test Data

AREA (A) = 32 SQ CM

SAMPLE
LENGTH (L) = 10 CM $K = \frac{QL}{Aht}$

CONSTANT
HEAD (h) = 37 CM

YELLOW SAND

DENSITY = 91 PCF

TIME t sec	Q cc	YELLOW SAND K cm/sec
90	175	1.69e-02
90	235	2.27e-02
90	248	2.40e-02
90	268	2.59e-02
90	255	2.47e-02
90	260	2.52e-02
AVG K =		2.32e-02

EPK WHITE
FINE SILICA
QUARTZ SAND

AREA (A) = 32 SQ CM

SAMPLE
LENGTH (L) = 13 CM $K = \frac{QL}{Aht}$

CONSTANT
HEAD (h) = 30 CM

TIME t sec	Q cc	K cm/sec	WHITE SAND DENSITY =81 PCF
90	108	1.61e-02	
90	113	1.69e-02	
90	108	1.61e-02	
90	110	1.64e-02	
90	109	1.63e-02	
AVG K =		1.64e-02	

A.10 Falling Head Permeability Test Data

FALLING
HEAD
PERMEABILITY
TEST

50% KAOLINITE CLAY
50% FINE SILICA SAND

SAMPLE LENGTH (L) = 4 CM
STANDPIPE AREA (a) = 1.54 SQ CM
SAMPLE AREA (A) = 31.7 SQ CM

$$K = \frac{aL}{At} \ln \frac{h_1}{h_2}$$

TIME t sec	h1 cm	h2 cm	GRADUATED CYLINDER FLOW Q ml	BURETTE FLOW Q ml	K cm/sec
88	94	92	6	4	5.69e-05
237	91	84	12	12	6.77e-05
445	82	70	17	20	6.87e-05
328	69	62	12	12	6.51e-05
129	61	58	5	4	6.07e-05
140	57	55	4	4	5.95e-05
147	54	51	4	4	6.06e-05
154	50	48	4	4	6.21e-05

AVERAGE K 6.27e-05

A.11 Atterberg Limits

50% Sand -- 50% Kaolinite Clay
Plastic Limit PL=20.3
Liquid Limit LL=31.8

A.12 Derivation of Formulas for BAT Permeability Calculations

The following provides the derivation of the formulas that are used by the program "Perm" Version 13 obtained from the BAT Invitech Company for calculating the coefficient of permeability. The derivations were provided by the BAT Invitech Company.

Symbols:

- K = permeability (m/s)
- t = time (s)
- q = flow of water per unit time (m³/s)
- F = geometric flow factor (m)
- l = length of filter (m)
- d = diameter of filter (m)
- A = internal cross sectional area of system (m²)
- g = acceleration of gravity (m/s²)
- r = density of water (kg/m³)
- u₀ = absolute initial pore water pressure (kPa)
- u_t = absolute pore water pressure at time t (kPa)
- h₀ = initial water column height above filter (m)
- h_t = height of water column above filter at time t (m)
- V₀ = initial gas volume in system (m³)
- V_t = gas volume at time t (m³)
- p₀ = absolute initial measured gas pressure in system (kPa)
- p_t = absolute measure gas pressure at time t (kPa)
- T₀ = initial temperature of gas in system (°K)
- T_t = temperature of gas at time t (°K)

Darcy's Law:(1)

$$q = kF \frac{u_0 - u_t}{gr}$$

Equation of Continuity:(2)

$$dV_t = -qdt$$

Combining Darcy's Law and the Equation of Continuity yields(3):

$$k = \frac{gr}{F} \frac{1}{u_0 - u_t} \left(-\frac{dV_t}{dt} \right)$$

Given Boyle's - Marriotte's Law:(4)

$$V_t = \frac{T_t}{T_0} \frac{p_0}{p_t} V_0$$

Taking the derivative of Boyle's - Marriotte's Law yields (5,6,7):

$$\begin{aligned} \frac{dV_t}{dt} &= \frac{dV_t}{dT} \frac{dT}{dt} + \frac{dV_t}{dp} \frac{dp}{dt} \\ \frac{dV_t}{dT} &= \frac{1}{T_0} \frac{p_0}{p_t} V_0 \\ \frac{dV_t}{dp} &= \frac{T_t}{T_0} \frac{p_0}{p_t^2} V_0 \end{aligned}$$

By combining the above three equations yields (8,9):

$$\begin{aligned} \frac{dV_t}{dt} &= \frac{1}{T_0} \frac{p_0}{p_t} V_0 \frac{dT_t}{dt} \left(-\frac{T_t}{T_0} \frac{p_0}{p_t^2} V_0 \frac{dp_t}{dt} \right) \\ \frac{dV_t}{dt} &= \frac{T_t}{T_0} \frac{p_0}{p_t} V_0 \left(\frac{1}{T_t} \frac{dT_t}{dt} - \frac{1}{p_t} \frac{dp_t}{dt} \right) \end{aligned}$$

Definition of a water column height (10):

$$h_t = h_0 + \frac{(V_0 - V_t)}{A}$$

Relationship between pore pressure and measured pressure (11):

$$u_t = p_t + grh_t$$

Combining equations (3), (9), (10), and (11) yields (12):

$$k = \frac{gr}{F} \frac{p_0 V_0}{T_0} \frac{T_t}{p_t} \left(\frac{1}{u_0 - p_t - grh_t} \right) \left(\frac{1}{p_t} \frac{dp_t}{dt} - \frac{1}{T_t} \frac{dT_t}{dt} \right)$$

For purpose of numerical calculation, k is calculated at a time t which is midway between two measurements. h_t , V_t , and p_t are assumed to have values midway between those computed for the actual time of measurement. dp_t/dt and dT_t/dt are approximated by the slope of the p_t vs. t and T_t vs t curves, computed by the least squares method using four measured data points, two from before and two from after time t (one before and one after for the first and last calculation).

If temperature is neglected the equation reduces to (13):

$$k = \frac{gr}{F} \frac{p_0 V_0}{p_t} \left(\frac{1}{u_0 - p_t - grh_t} \right) \left(\frac{1}{p_t} \frac{dp_t}{dt} \right)$$

where the Flow Factor, F is calculated from the following equation (14):

$$F = \frac{2\pi l}{\ln\left[\frac{l}{d} + \sqrt{1 + \left(\frac{l}{d}\right)^2}\right]}$$

A check of the units in equation 13 yields:

$$\begin{aligned} \frac{\frac{m}{\text{sec}^2} * \frac{Kg}{m^3}}{m} * m^3 * \frac{m^2}{KN} * \frac{1}{\text{sec}} \\ = \frac{Kg}{\text{sec}^2} * \frac{m^2}{KN * \text{sec}} \end{aligned}$$

$$\begin{aligned} \frac{Kg * m^2}{\text{sec}^3 * KN} * \frac{1 KN}{1000 N} * \frac{1 N}{\frac{Kg * m}{\text{sec}^2}} = \\ \frac{Kg * m^2}{\text{sec}^3} * \frac{\text{sec}^2}{Kg * m} = \frac{m}{\text{sec}} \end{aligned}$$

This check shows that the equation supplied by the BAT developers does indeed have units of m/sec. However, it also shows a conversion factor of 0.001 is not readily noticeable in the equation.

The following comments are provided by the developers of the program "Perm" for use of their program.

1. The program will ask if temperature is measured. Reply 'Y' (for yes) or 'N' (for no). If the answer is no, the program will be identical with the previous version.
2. The program asks for the cross-sectional area of the (glass) test container in cm². The standard value is 1.96 for 35 mL vials.
3. The start level is the height of the water column in the vial, plus 0.19 m. For inflow test, this will normally be

$0.00 + 0.19 = 0.19$ m. For an outflow test, 30 mL of water in a 35 mL vial usually gives a value near $0.17 + 0.19 = 0.36$ m.

4. The start temperature is that read just prior to the test, in degrees Celsius ($^{\circ}\text{C}$).

5. The transducer correction factor is specific for each transducer. It is usually determined by slowly changing the temperature of a water bath in which the transducer is submerged at constant depth, and observing the change in displayed pressure per unit change in temperature ($\text{m H}_2\text{O}/^{\circ}\text{C}$). The program assumes that this factor is linear. A typical value is $0.013 \text{ m H}_2\text{O}/^{\circ}\text{C}$.

6. The data entry section of the program will ask first for the time (in hours, minutes and seconds), then for the pressure ($\text{m H}_2\text{O}$) at that time, and finally for the temperature ($^{\circ}\text{C}$). As before, a negative time will terminate data entry. The option will then be given of examining the data, which may be corrected. A chance to examine all the intermediate values of calculated permeability will also be given, so that the stability of the calculation may be ascertained.

7. When no more data is entered, the data is plotted and optionally printed in tabular form. The plot contains four axes; pressure, time, temperature and permeability. Pressure vs time is plotted as a solid line. Temperature vs time is plotted as a dotted line. Permeability vs time is plotted as individual points (asterisks).

A hand solution to equation (13) is provided for the first trial of section A.3.

$$k = \frac{gr}{F} \frac{p_0 V_0}{p_t} \left(\frac{1}{u_0 - p_t - grh_t} \right) \left(\frac{1}{p_t} \frac{dp_t}{dt} \right)$$

$$\begin{aligned}
 P_0 &= -9.16m * \frac{1000 \text{ Kg}}{m^3} * \frac{9.8 \text{ N}}{1 \text{ Kg}} * \frac{1 \text{ KN}}{1000 \text{ N}} = -89.8 \text{ kPa} \\
 P_t &= -8.92m * 9.8 = -87.4 \text{ kPa} \\
 V_t &= \frac{P_0 * V_0}{P_t} = \frac{-89.8 * 3.65E-5}{-87.4} = 3.75E-5 \text{ m}^3
 \end{aligned}$$

$$\begin{aligned}
 h_t &= h_0 + \frac{V_0 - V_t}{A} = 0.19 + \frac{3.65E-5 - 3.75E-5}{1.96E-4} = .185m \\
 grh_t &= .185 * \frac{1000 \text{ Kg}}{m^3} * \frac{9.8 \text{ N}}{1 \text{ Kg}} * \frac{1 \text{ KN}}{1000 \text{ N}} = 1.813 \text{ kPa} \\
 u_0 &= .24 * 9.8 = 2.35 \text{ kPa}
 \end{aligned}$$

$$\begin{aligned}
 \frac{gr}{F} &= \frac{9.8 * 1000}{.28515} = 34367.9 \frac{\text{Kg}}{\text{sec}^2 * m^3} \\
 \frac{1}{u_0 - P_t - grh_t} &= 2.35 + 87.4 - 1.81 = .001137 \frac{m^2}{KN} \\
 \frac{1}{P_t} * \frac{dP_t}{dt} &= \frac{1}{-87.4} * \frac{-89.8 + 87.4}{5} = .005492
 \end{aligned}$$

$$\begin{aligned}
 k &= 34367.9 * 3.75E-5 * 0.01137 * 0.005492 * .001 = \\
 &\quad 8E-8 \frac{m}{\text{sec}} \\
 &= 8E-6 \frac{cm}{\text{sec}}
 \end{aligned}$$

A spreadsheet solution using equation 13 is shown below. The permeability is calculated between the two time readings. The least squares method is not used.

BAT PERM DATA

TIME	PRESSURE	$V_t =$		1	$1 * dp_t$	
sec	m H ₂ O	$p_o V_o / p_t$	h_t	$u_o - p_t - gr h_t$	$p_t * dt$	k
		m ³	m	m ² /KN	1/sec	cm/sec
0	-9.16					
5	-8.92	3.75E-5	0.185	0.0138	-0.0053	-9.63E-6
10	-8.67	3.86E-5	0.179	0.0142	-0.0056	-1.07E-5
15	-8.27	4.04E-5	0.170	0.0149	-0.0072	-1.49E-5
20	-7.68	4.35E-5	0.154	0.0159	-0.0096	-2.30E-5
25	-6.48	5.16E-5	0.113	0.0181	-0.0165	-5.33E-5
30	-4.34	7.70E-5	-0.017	0.0215	-0.0370	-2.11E-4
35	-1.39	2.41E-5	-0.851	0.0102	-0.1597	-1.35E-3
40	-0.32	1.04E-5	-4.954	0.0021	-0.6906	-5.15E-3
45	-0.24	1.39E-3	-6.731	0.0015	-0.8259	-6.07E-3
50	-0.21	1.59E-3	-7.747	0.0013	-0.8523	-6.23E-3

APPENDIX B
ORGANIC CHEMICAL DATA

MW	COMPOUND	ION	FORMULA
78	Benzene	78(52,71)	C ₆ H ₆
156	Bromobenzene	77(156,158)	C ₆ H ₅ Br
128	Bromochloromethane	128(49,130)	CH ₂ Br
162	Bromodichloromethane	83(85,127)	CHCl ₂ Br
250	Bromoform	173(252,175)	CHBr ₃
134	n-Butylbenzene	91(92,134)	C ₁₀ H ₁₄
134	sec-Butylbenzene	105(134)	C ₁₀ H ₁₄
134	tert.-Butylbenzene	119(91,134)	C ₁₀ H ₁₄
152	Carbontetrachloride	117(119,121)	CCl ₄
112	Chlorobenzene	112(114,77)	C ₆ H ₅ Cl
118	Chloroform	83(85,47)	CHCl ₃
126	2-Chlorotoluene	126(91)	C ₇ H ₇ Cl
126	4-Chlorotoluene	126(91)	C ₇ H ₇ Cl
206	Dibromochloromethane	127(129)	CHClBr ₂
234	1,2-Dibromo- 3-chloropropane	157(75,155)	C ₃ H ₅ ClBr ₂
186	1,2-Dibromoethane(EDB)	107(109,188)	C ₂ H ₄ Br ₂
172	Dibromomethane	93(95,174)	CH ₂ Br ₂
146	1,2-Dichlorobenzene	146(111,148)	C ₆ H ₄ Cl ₂
146	1,3-Dichlorobenzene	146(111,148)	C ₆ H ₄ Cl ₂

146	1,4-Dichlorobenzene	146(111,148)	$C_6H_4Cl_2$
98	1,1-Dichloroethane	63(65,83)	$C_2H_4Cl_2$
98	1,2-Dichloroethane	62(64,98)	$C_2H_4Cl_2$
96	1,1-Dichloroethene	96(61,63)	$C_2H_2Cl_2$
96	cis-1,2-Dichloroethene	96(61,98)	$C_2H_2Cl_2$
96	trans-1,2-Dichloroethene	96(61,98)	$C_2H_2Cl_2$
112	1,2-Dichloropropane	63(112,62,41)	$C_3H_6Cl_2$
112	1,3-Dichloropropane	76(78)	$C_3H_6Cl_2$
112	2,2-Dichloropropane	77(97)	$C_3H_6Cl_2$
110	1,1-Dichloropropene	110(75,77)	$C_3H_4Cl_2$
110	cis-1,3-Dichloropropene	75(77,110)	$C_3H_4Cl_2$
110	trans-1,3-Dichloro propene	75(77,110)	$C_3H_4Cl_2$
106	Ethylbenzene	106(91)	C_8H_{10}
258	Hexachlorobutadiene	225(260)	C_4Cl_6
120	Isopropylbenzene	105(120)	C_9H_{12}
134	p-Isopropyltoluene	119(134,91)	$C_{10}H_{14}$
84	Methylene chloride	84(49,51,86)	CH_2Cl_2
128	Naphthalene	128	$C_{10}H_8$
120	n-Propylbenzene	120(91)	C_9H_{12}
104	Styrene	104(103,78)	C_8H_8
166	1,1,1,2-Tetrachloroethane	131(133,119)	$C_2H_2Cl_4$

166	1,1,2,2-Tetrachloroethane	83(131,85)	$C_2H_2Cl_4$
164	Tetrachloroethene(PERC)	164(129,131)	C_2Cl_4
92	Toluene	92(91,65)	C_7H_8
180	1,2,3-Trichlorobenzene	180(182)	$C_6H_3Cl_3$
180	1,2,4-Trichlorobenzene	180(182)	$C_6H_3Cl_3$
132	1,1,1-Trichloroethane	97(99,117)	$C_2H_3Cl_3$
132	1,1,2-Trichloroethane	97(83,85)	$C_2H_3Cl_3$
130	Trichloroethene(TCE)	130(95,97)	C_2HCl_3
146	1,2,3-Trichloropropane	75(77,110)	$C_3H_5Cl_3$
120	1,2,4-Trimethylbenzene	105(120)	C_9H_{12}
120	1,3,5-Trimethylbenzene	105(120)	C_9H_{12}
106	o-Xylene (1,2 Dimethyl benzene)	106(91)	C_8H_{10}
106	m,p-Xylene	106(91)	C_8H_{10}

INTERNAL STD/SURR

174	BROMOFLUOROBENZENE	95(174,176)	C_6H_4FBr
96	FLUOROBENZENE	96(77)	C_6H_5F
128	BROMOCHLOROMETHANE	128(49,130)	CH_2Br

APPENDIX C
BAT FIELD SAMPLING LOG

C.1 Cavalier Site

17 October 1991 MW-17 Water Table Depth-9'-6"

BAT MK2(Steel) pushed to depth of 13'-1"

Cascaded sampling

BAT1 full and BAT2 12 ml in 34 minutes.

BAT3 full and BAT4 2 ml in 65 minutes.

BAT5 full and BAT6 0.5 ml in 30 minutes.

BAT MK2(HDPE) pushed to depth of 11'-6".

Cascaded sampling

BAT7 full and BAT8 3 ml in 40 minutes.

23 October 1991 MW-17 Water Table Depth 9'-6"

BAT MK2 pushed to depth of 10'-6".

Purged smelled aromatics.

Cascaded sampling

BAT1 recovered 15 ml in 60 minutes.

BAT2 recovered 15 ml in 40 minutes.

Single sampling-BAT3 recovered 8 ml in 16 minutes.

Same probe pushed to depth of 13'.

BAT samples 4 and 5 each recovered 1 ml in 25
minutes (single tube sampling).

29 October 1991 MW-17 Water Table Depth-9'-10"

BAT probe (steel) sampling inside MW-17 at 10' depth.

BAT cascaded samples 1,3,5,7 contained no headspace.

BAT samples 2,4,6,8 contained 25% headspace.

Sampling time in minutes were 14,10,10, and 10 respectively.

10 February 1992 MW-15 Water Table Depth-8'-6"

MW-15 purged of 4 well volumes--smelled aromatics and sulfur.

Sampled well with teflon bailer--2, 40 ml vials filled.

Placed BAT MK2 (HDPE) probe inside MW-15 and purged.

Cascaded Sampling

Sampled 4.5 minutes--BAT1 full--BAT2 50% full

Sampled 5.5 minutes--BAT3 full--BAT4 75% full

Sampled well with teflon bailer--2, 40 ml vials filled.

Cascaded Sampling

Sampled 6.5 minutes--BAT5 full--BAT6 80-85% full.

Sampled 6 minutes--BAT7 full--BAT8 75% full.

Sampled 6 minutes--BAT9 full--BAT10 40% full.

C.2 Textile Town Site

26 November 1991 MW-11(PERC) Water Table Depth-6'

BAT MK2 pushed to depth of 6'-6".

Problem getting samples only approximately 5 ml.

BAT MK2 pushed to depth of 9'-10".

Problem filter clogged or septum needs replacing.

Enviroprobe pushed to a depth of 6.5 feet.

27 November 1991 MW-11(PERC)

BAT MK2(Steel) pushed to a depth of 7'-4".

Problems obtaining samples only approximately 5 ml.

Same BAT MK2(Steel) pushed to a depth of 8'-6".

Still problems obtaining samples.

Enviroprobe pushed to a depth of 8'-6".

Purged 4 minutes recovered 10 ml.

Purged 4 minutes recovered 15 ml.

Cascaded Sampling BAT3 recovered 30 ml in 29 minutes.

Cascaded Sampling BAT5 recovered 30 ml in 22 minutes.

3 December 1991 MW-7(BTEX) Water Table Depth- 7'-8"

BAT MK2 pushed to a depth of 8'-2".

Problem with septum needs replacing no samples
obtained.

Enviroprobe pushed to a depth of 8'-2".

Cascaded sampling

BAT1 recovered full sample (35 ml) in 21 minutes.

BAT3 recovered full sample in 6 minutes.

Second BAT MK2 pushed to a depth of 7'-11".

Sample 1 recovered 32 ml in 24 minutes.

Sample 2 recovered 21 ml in 32 minutes.

6 December 1991 MW-7(BTEX)

Vertical contamination of Benzene

BAT MK2

9 foot depth	Purged (no odor)
11 foot	purged for 5 min (aromatics present) retrieved 12 ml. 30 ml sample in 22 minutes.
12 foot	purged for 5 min (aromatics present) retrieved 18 ml. 35 ml (full) sample in 15 ml.
13 foot	only recovered 2 ml in 7 minutes. May have reached confining layer.

Enviroprobe

11 foot depth	purged 4 min (aromatics present) retrieved 15 ml. Sample recovered 34.5 ml in 22 min. Full sample recovered in 30 min plus 2 ml in upper tube.
---------------	--

10 December 1991 MW-11(PERC) Water Table Depth-6'-6"

Vertical contamination testing for PERC.

BAT MK2

7 foot depth

8 foot depth-purged 2.5 min retrieved 21 ml.

sample of 30 ml in 4.5 min.

9 foot depth-purged 2 min got 10 ml.

sample of 30 ml in 22.5 min.

10 foot depth-purged 2.75 min retrieved 10 ml.

sample of 12-15 ml in 36 min.

sample of 12 ml in 21 min.

11 foot depth-purged 3.75 min retrieved 7 ml.

sample of 30 ml in 35 min.

12 foot depth-purged 4 min retrieved 13 ml.

sample of 20 ml in 12 min.

13 foot depth-purged 3.5 min retrieved 17 ml.

sample of 33 ml in 9.5 min.

17 December 1991 MW-11(PERC) Water Table Depth-6'-9"

BAT MK2 sampling inside MW-11 for PERC-depth 7'.

Purge 30 seconds recovered 30 ml.

Cascaded Sampling at 7' depth inside MW-11.

BAT1 full (35 ml) and BAT2 (25-30 ml) in 3 minutes.

BAT3 full (35 ml) and BAT4 (25-30 ml) in 3 minutes.

Cascaded Sampling at 10' depth inside MW-11.

Purged for 30 sec retrieved 30 ml.

Full sample in 3.5 minutes.

Cascaded Sampling at 12' depth inside MW-11.

Purged for 40 sec retrieved 30 ml.

Full sample in 3.75 minutes.

8 January 1992 MW-7(BTEX) Water Table Depth-7'-7"

Test one with Vacuum Pump/Erlenmeyer flask

Enviroprobe--depth 11'-6"

Purged 4 min obtained approximately 18 ml.

BAT recovered 23 ml in 10 minutes.

BAT1 recovered full sample in 28 minutes and upper
tube (BAT2) recovered 16 ml.

BAT3 recovered full sample in 26 minutes and upper
tube (BAT4) recovered 16 ml.

Sampled using Erlenmeyer flask and vacuum pump.

BAT5 recovered full sample in 105 min and BAT6
(upper tube) recovered 28 ml.

10 January 1992 MW-7(BTEX)

Testing with Vacuum Pump/Erlenmeyer Flask

BAT pushed to a depth of 11'-6"

Purged 4 min retrieved 22 ml (smelled aromatics)

Cascaded sampling

BAT1 full in 23 minutes-BAT2 recovered 20 ml.

BAT3 full in 20 minutes-BAT4 recovered 1 ml.

Vacuum pump testing

Purged 5 min approximately 50 ml.

Sampled 6 min into Nalgene flask recovered 100 ml.

Sampled 6 min into Glass flask recovered 100 ml.

Cascaded sampling

BAT5 full sample in 42 minutes.

16 January 1992 MW-7(BTEX)

Plume chasing

1st Penetration (Enviroprobe)

14'6" from MW-7 at a depth of 11'-6".

Purged 4 min retrieved 29 ml.

Full sample recovered in 32 minutes.

2nd Penetration (BAT MK2 w/steel filter)

27'-6" from MW-7 at a depth of 11'.

Purged 10 min retrieved 15 ml.

Full sample recovered in 60 minutes along with 12 ml of upper test tube.

3rd Penetration (BAT MK2 w/HDPE filter)

35' from MW-7 at a depth of 11'.

Purged 7 min retrieved 10 ml.

Full sample recovered in 67 minutes along with 8 ml of upper test tube.

18 February 1992 MW-7 (BTEX) Water Table Depth-6'-1"

Testing of 3/4" bailer inside drill rods.

MW-7 purged of 4 well volumes and then sampled--2 40 ml vials.

BAT MK2 HDPE filter no septum with tape pushed to 11'-6".

No sample.

BAT MK2 Steel filter no septum or tape pushed to 11'-6".

No sample.

Applied vacuum pump to drill rods but still no sample.

Conventional BAT sampling.

1. BAT MK2 Steel Filter pushed to depth of 11'-6".
2 cascaded samplings yielded vials with no head space.
Sampling times--33 and 31 minutes
2. Enviro probe with HDPE filter pushed to depth of 11'-6".
2 cascaded samplings yielded vials with no head space.
Sampling times--20 and 13 minutes
2 Single vial samplings
Sampling time 6 and 3 minutes yield 31 ml each (12-14% head space).

APPENDIX D
CHEMICAL ANALYSES DATA

D.1 GC/MS Data for Cavalier Site

Concentration = %BFB X Response Factor X Dilution Factor
BFB (Bromofluorobenzene)-Internal Standard

Response Factors	
Benzene (B)	.01077
Toluene (T)	.01525
Ethylbenzene (EB)	.02742
m,p-Xylene (m,p-X)	.00157
o-Xylene (o-X)	.02493
Tetrachloroethene (PERC)	.04103
Trichloroethene (TCE)	.03091
Napthalene (N)	.05403

Analyses Date--19 Oct 91 Sampling Date--17 Oct 91

Bailer1 run at 200:1 dilution (.5ml into 100 ml) all other samples run at 100:1 dilution.

Sample	B	T	EB	m,p-X	o-X
Bailer1	24 (0.2)	7198 (43.3)	3120 (10.4)	3900 (31.5)	3980 (14.5)
BAT1	0	71.5 (46.9)	25.0 (9.1)	33.1 (30.5)	35.3 (13.3)
Bailer2	20 (18.6)	4410 (2892.3)	2606 (950.6)	3671 (2493.1)	2884 (1472.8)
BAT3	0	56.3 (36.9)	18.6 (6.8)	25.6 (30.6)	35.4 (10.3)
BAT7	0	30.5 (20.0)	28.8 (10.5)	8.7 (3.5)	0
BAT5	0	21.0 (13.8)	28.5 (10.4)	4.7 (1.9)	0

BAT9	0	8.3	0	0	3.4
Bailer3	9.9 (4.6)	6724 (2204.7)	3301 (602.0)	4032.1 (1735.3)	4015.5 (808.7)

Analyses Date--24 Oct 91 Sampling Date--23 Oct 91

All samples run at 1:200 dilution (.5 ml into 100 ml)
Dilution factor--200

Concentration in ppb
(% BFB)

Sample	B	T	EB	m,p-X	o-X	N
BAT1	65 (30.4)	1426 (467.7)	148 (27.0)	235 (101.4)	243 (48.8)	2.2 (0.2)
BAT2	93 (43.2)	1920 (629.5)	232 (42.3)	353 (152.4)	367 (73.7)	
BAT3	120 (55.6)	3060 (1003.2)	601 (111.2)	952 (411.5)	953 (191.2)	
BAT4	31 (14.4)	790 (259.0)	94 (17.1)	165 (71.5)	172 (34.5)	
Bailer1	3 (1.3)	5591 (1833.1)	2751 (501.7)	3361 (1452.5)	3323 (666.4)	479 (44.3)
Bailer2 (dup1)	334 (526.6)	6470 (2383.7)	2811 (658.5)	3283 (1764.4)	3415 (845.4)	599 (129.5)
Bailer3	9 (4.3)	6084 (1995.0)	2946 (537.2)	3706 (1601.6)	3891 (780.3)	525 (48.6)
Bailer4 (dup3)	4.7 (2.2)	7912 (1297.1)	2991 (272.7)	4279 (924.5)	3848 (385.9)	672 (31.1)

Analyses Date--30 Oct 91 Sampling Date--29 Oct 91

Samples Bailer3, BAT2, BAT4, and BAT6 were diluted by injecting 200 ul into 200 ml (1:1000 dilution).

Samples BAT1, Bailer1, BAT3, Bailer 2, and BAT5 were diluted by injecting 500 ul into 200 ml (1:400 dilution).

Concentration in ppb

(% BFB)						
Sample	B	T	EB	m,p-X	o-X	N
BAT1	44 (10.3)	5700 (934.4)	2253 (205.4)	3479 (751.7)	2803 (281.1)	395 (18.3)
Bailer1	7 (1.7)	5494 (900.7)	2270 (207.0)	3310 (715.3)	2836 (284.4)	
BAT3	0	6602 (1082.3)	2546 (232.1)	3839 (829.5)	3381 (339.0)	
Bailer2	0	6147 (1007.7)	2449 (223.3)	3552 (767.6)	3031 (304.0)	
BAT5	0	7514 (1231.9)	2761 (252.7)	4107 (887.5)	3635 (364.5)	
Bailer3	0	6631 (434.8)	2235 (81.5)	3834 (331.4)	2967 (119.0)	
BAT2	0	6390 (419.0)	2015 (73.5)	3420 (295.6)	2827 (113.4)	
BAT4	0	6233 (408.7)	1862 (67.9)	3374 (291.6)	2735 (109.7)	
BAT6	0	8863 (581.2)	2547 (92.9)	4753 (410.8)	3864 (155.0)	

D.2 GC/MS Data for Textile Town Site

Concentration = %BFB X Response Factor
BFB (Bromofluorobenzene)

Response Factors

Benzene (B)	.01077
Toluene (T)	.01525
Ethylbenzene (EB)	.02742
m,p-Xylene (m,p-X)	.00157
o-Xylene (o-X)	.02493
Tetrachloroethene (PERC)	.04103
Trichloroethene (TCE)	.03091

Concentration in ppb (% BFB)

Analyses Date--4 Dec 91

Sampling Date--3 Dec 91

Sample	B	T	EB	m,p-X	o-X
--------	---	---	----	-------	-----

Bailer1	107 (99.7)	49 (32.2)	45 (16.4)	45 (39.3)	40 (16.1)
BAT1	0	0.6 (39.2)	0.05 (1.9)	0.33 (28.8)	0.28 (11.1)
Bailer3	65 (60.3)	0	0	0	0
BAT3	0	1.2 (81.0)	0.45 (16.5)	0.91 (78.4)	0.83 (33.1)
BAT5	0.1 (8.9)	0.8 (55.2)	0.30 (11.1)	0.65 (56.0)	0.61 (24.4)
Bailer2	48.6 (4518.4)	0.26 (17.2)	13.2 (543.5)	7.2 (621.4)	0.65 (26.2)
Bailer4	43.8 (4065.2)	0.26 (17.1)	13.2 (482.9)	7.0 (605.0)	0.72 (29.0)
BAT2	0	0.12 (7.1)	0	0.06 (4.9)	0

Analyses Date--9 Dec 91

Sampling Date--6 Dec 91

Sample	B	T	EB	m,p-X	o-X
BAT1	2.4 (225.2)	0	0	0	0
BAT2	17.95 (1667.3)	0.98 (64.4)	1.51 (55.2)	1.42 (123.3)	0.81 (32.5)
BAT4	38.0 (3532.3)	0.84 (54.8)	0.71 (25.8)	0.86 (74.1)	0.54 (21.4)
BAT7	20.75 (1926.7)	0.93 (61.2)	0.26 (9.5)	0.50 (43.3)	0.4 (16.0)
BAT8	24.3 (2258.8)	1.29 (84.9)	0.38 (13.9)	0.65 (56.4)	0.54 (21.8)
BAT3	22.7 (3101.3)	1.1 (106.9)	0.79 (42.1)	1.00 (127.0)	0.61 (35.7)

Analyses Date--11 Dec 91

Sampling Date--10 Dec 91

Bailer	PERC	TCE	BAT	PERC	TCE
1	21.7 (529.4)	0.48 (15.5)	7	0	0

3	20.48 (499.1)	0.43 (14.0)	2	0	0
			4	0	0
			6	0	0
			5	0	0
			3	0	0

Analyses Date--18 Dec 91

Sampling Date--17 Dec 91

	Bailer1	BAT1	BAT6	BAT9	Bailer3	Bailer4
PERC	23.8 (579.7)	17.2 (418.8)	17.8 (433.3)	16.1 (392.3)	20.5 (500.5)	25.0 (610.4)

Analyses Date--9 Jan 92

Sampling Date--8 Jan 92

Sample	B	T	EB	m,p-X	o-X
Bailer1	4.1 (377.2)	0 (0)	0.6 (21.0)	0.5 (40.4)	0 (0)
Bailer2	3.1 (289.5)	0 (0)	0.5 (18.9)	0.4 (33.5)	0 (0)
BAT3	24.7 (2292.2)	0.3 (20.9)	0.5 (16.9)	0.4 (34.2)	0.02 (0.9)
Bailer3	5.4 (497.4)	0 (0)	0.7 (24.4)	0.6 (53.9)	0 (0)
BAT1	25.8 (2395.7)				
BAT5	39.2 (3635.6)				

Analyses Date--13 Jan 92

Sampling Date--10 Jan 92

Sample	B	T	EB	m,p-X	o-X
Vacuum Flask3	0.9 (82.5)	0 (0)	0 (0)	0 (0)	0 (0)

BAT1	23.3 (2165.0)	0.2 (12.2)	0.04 (1.4)	0.2 (17.4)	0.09 (3.5)
Nalgene Flask1	1.2 (114.1)	0 (0)	0 (0)	0 (0)	0 (0)
BAT3	16.6 (1543.7)	0.2 (13.0)	0 (0)	0.15 (12.9)	0.11 (4.5)
Vacuum Flask4	0.8 (78.2)	0 (0)	0 (0)	0 (0)	0 (0)
BAT5	37.6 (3495.7)	0.2 (15.2)	0.2 (8.6)	0.4 (38.5)	0.2 (7.1)

Analyses Date--17 Jan 92

Sampling Date--16 Jan 92

Sample	B	T	EB	m,p-X	o-X
BAT8	0.16 (14.8)	0.25 (16.3)	0 (0)	0.11 (9.3)	0.10 (4.1)
BAT5	0 (0)	0.3 (21.5)	0 (0)	0.09 (7.6)	0.05 (2.2)
BAT2	3.6 (333.3)	0.17 (11.2)	0 (0)	0.06 (5.3)	0 (0)
BAT1	2.95 (274.1)	0 (0)	0 (0)	0 (0)	0 (0)

Analysed Date--19 Feb 92

Sampling Date--18 Feb 92

BAT1 diluted by factor of 10 all other samples diluted by factor of 20.

Sample	B	T	EB	m,p-X	o-X
Bailer Equip Blank	0	0	0	0	0
Enviro Probe Blank	0	0	0	0	0
Bailer1	95 (442.4)	2 (5.9)	18 (33.6)	11 (46.7)	9 (17.1)
Bailer2	108	2	21	13	10

					204
	(499.4)	(7.5)	(38.7)	(55.9)	(19.5)
BAT1	247 (2297.3)	13 (84.9)	88 (319.5)	42 (366.5)	91 (367.0)
BAT3	323 (1499.9)	14 (46.1)	110 (200.0)	52 (226.1)	109 (219.3)
BAT5	210 (973.7)	4 (12.5)	5 (9.1)	4 (17.1)	7 (13.4)
BAT7	176 (817.8)	5 (15.9)	6 (10.2)	5 (19.7)	6 (12.8)
BAT9	205 (953.1)	4 (12.7)	5 (9.5)	4 (19.0)	6 (12.9)
BAT10	198 (917.0)	4 (14.1)	7 (12.6)	5 (22.9)	8 (16.1)

APPENDIX E DECONTAMINATION PROCEDURES

E.1 Bailer Decontamination

1. Boil distilled/deionized water and mix with Alconox or Sparkleen in a large container until sufficient soap is present. Add additional distilled water to cool.
2. Disassemble the teflon bailer and place in the Sparkleen solution. Using a brush with a long arm clean the exterior and interior of the bailer along with the disassembled parts (top, bottom, and ball).
3. Rinse three times with distilled/deionized water.
4. Spray with isopropyl alcohol. (optional)
5. Lay bailer on aluminum foil until air dried.
6. Upon drying, wrap the bailer in the aluminum foil for transport to the field.

E.2 Decontamination of BAT Glass Sample Vials

1. Boil distilled/deionized water and mix with Alconox or Sparkleen in a large container until sufficient soap is present. Add additional distilled water to cool.
2. Place glass vials in the solution. Clean the interior and exterior of the vials with a test tube brush.
3. Rinse with distilled/deionized water at least three times

until no soap is present. If stubborn stains or deposits are present a small amount of methanol may be placed in the vial, shaken, and then discarded.

4. Place the glass vials in an oven at 90 degrees Celsius until the glass is dried.

5. After removing the vials from the oven place ends over the vials to avoid any contamination and store until use.

E.3 BAT Probe Decontamination

1. Upon retrieval, remove all soil deposits from the BAT probe with a brush and water.

2. At the lab boil distilled/deionized water.

3. Place the BAT probe into a bucket and lean it against the side. Fill the bucket with water but allow the top of the BAT to extend above the water.

4. Using a 60 ml syringe pull several (5) full syringes of water through the filter and the BAT probe.

5. Air dry the BAT probe and store for future use. The BAT can be placed in another bucket of water and water pulled through the sample to serve as an equipment blank which can be analyzed to ensure the cleaning procedure was adequate. If adequately cleaned, the BAT probe can also be wrapped in aluminum foil for storage.

6. Additional cleaning inside the BAT probe can be done by unscrewing the septum nut on top of the BAT along with the rubber septum. A small test tube brush can be used to clean

this area.

E.4 Decontamination of Enviro Probe

1. Wash the Enviro probe with potable water to remove all soil deposits.
2. Unscrew the septum locking device, remove the internal metal rod, and remove the guide sleeve which covers the porous filter while being deployed.
3. Remove the cone from the rod and remove the porous filter.
4. Clean all metal parts with brush and warm soapy solution as above. Ensure all threaded connections are dried with a clean cloth to avoid rusting.
5. Reassemble device and change porous filter as required.

APPENDIX F
CONE PENETRATION DATA

F.1 CPT Sounding at Lynch Park Adjacent to MW-17

LYNCH PARK
CPT115.CPD

6 FEB 92

DEPTH m	qc MN/SQM	fs KN/SQM	Rf %	SOIL TYPE
0.5	1.35	-1.67	-0.12	UNDEFINED
1.0	1.39	-0.83	-0.06	UNDEFINED
1.5	5.50	-2.57	-0.05	UNDEFINED
2.0	14.16	92.95	0.66	SAND
2.5	6.77	21.96	0.32	SAND TO SILTY SAND
3.0	4.62	5.06	0.11	SAND TO SILTY SAND
3.5	11.22	20.62	0.18	SAND
4.0	13.43	58.99	0.44	SAND
4.5	15.04	127.24	0.85	SAND

F.2 CPT Sounding at Lynch Park Adjacent to MW-15

LYNCH PARK
CPT116.CPD

6 FEB 92

DEPTH m	qc MN/SQM	fs KN/SQM	Rf %	SOIL TYPE
0.5	1.97	-0.38	-0.02	UNDEFINED
1.0	2.35	-0.33	-0.01	UNDEFINED
1.5	6.91	0.52	0.01	SAND
2.0	11.66	12.29	0.11	SAND
2.5	10.83	75.80	0.70	SAND TO SILTY SAND
3.0	5.39	40.70	0.75	SAND TO SILTY SAND
3.5	8.64	52.91	0.61	SAND TO SILTY SAND
4.0	13.28	216.80	1.63	SAND TO SILTY SAND
4.5	24.98	158.97	0.64	SAND

F.3 CPT Sounding at Textile Town Around MW-11

TEXTILE TOWN

PERC MW

30 JAN 92

CPT113.CPD

DEPTH m	qc MN/SQM	fs KN/SQM	Rf %	SOIL TYPE
0.5	3.44	4.07	0.12	SAND TO SILTY SAND
1.0	2.87	-1.87	-0.07	UNDEFINED
1.5	3.18	-1.79	-0.06	UNDEFINED
2.0	1.56	-1.15	-0.07	UNDEFINED
2.5	3.00	-1.58	-0.05	UNDEFINED
3.0	8.98	58.05	0.65	SAND TO SILTY SAND
3.5	4.54	22.79	0.50	SAND TO SILTY SAND
4.0	10.89	101.84	0.94	SAND TO SILTY SAND
4.5	14.05	339.00	2.41	SILTY SAND TO SANDY SILT

F.4 CPT Sounding at Textile Town Around MW-7

TEXTILE TOWN

BTEX MW

30 JAN 92

CPT114.CPD

DEPTH m	qc MN/SQM	fs KN/SQM	Rf %	SOIL TYPE
0.5	2.59	-0.32	-0.01	UNDEFINED
1.0	2.96	-0.99	-0.03	UNDEFINED
1.5	4.05	-1.58	-0.04	UNDEFINED
2.0	2.28	-1.25	-0.05	UNDEFINED
2.5	6.98	20.35	0.29	SAND TO SILTY SAND
3.0	19.62	123.99	0.63	SAND
3.5	12.85	104.76	0.82	SAND TO SILTY SAND
4.0	13.32	46.06	0.35	SAND
4.5	15.88	319.94	2.02	SILTY SAND TO SANDY SILT

APPENDIX G HEADSPACE CORRECTIONS

This appendix shows the equations derived by Pankow (1986) which estimate the percent losses of volatile organic compounds that occur due to headspace left in sample vials. The derivation is based on a total mass balance. When a sample is placed in a vial with headspace present, some of the compound will remain in solution while some will partition into the gaseous phase in the headspace. The mass balance equation is as follows:

$$C_0 V_s = C_g V_g + C V_s$$

where:

- V_s = The volume of water solution (mL).
- V_g = The volume of gaseous headspace (mL).
- C_g = The concentration in the gaseous headspace (mol/mL).
- C = The concentration detected in the water solution (mol/mL).
- C_0 = True concentration which should be in the water solution (mol/mL).

Henry's Law describes the partitioning of a compound between the liquid and gaseous phases:

$$\frac{C_g}{C} = \frac{H}{RT}$$

where:

H = Henry's Law Constant (atm*m³/mol).

R = The gas constant (8.2 X 10⁻⁵ m³*atm/mol*deg).

T = Temperature (Kelvin).

Substitution of Henry's Law into the mass balance equation produces:

$$C_0 V_s = \left(\frac{H}{RT} \right) C V_g + C V_s$$

$$\frac{C_0}{C} = \frac{H}{RT} \frac{V_g}{V_s} + 1$$

$$\frac{C}{C_0} = \frac{1}{\left(\frac{H}{RT} \right) \left(\frac{V_g}{V_s} \right) + 1}$$

This equation was used to develop Figures G.1 and G.2 which show the remaining fraction in solution, C/C₀, for selected compounds versus various V_g/V_s ratios. Figure G.1 shows some values of several aromatic compounds. Ethylbenzene was omitted for clarity as its results nearly paralleled those of toluene. Figure G.2 shows several chlorinated compounds (PERC=tetrachloroethene, TCE=trichloroethene, chlorobenzene, carbon tetrachloride). Table G.1 gives the Henry's Law Constants which were used to prepare Figures G.1 and G.2. Figures G.1 and G.2 were developed for a temperature of 20 °C since water samples are normally warmed to room temperature before analysis. An example is provided below to demonstrate the use of the equation.

Example: What is the fraction of concentration of benzene ($H=.0055$) left in a water solution when it is stored at 20 °C and has a $V_g/V_s = .1$?

$$\frac{C}{C_0} = \frac{1}{\left(\frac{.0055}{8.2E-05 \times 293} \times .1 \right) + 1} = 0.9776$$

Table G.1 Henry's Law Constants for Selected Organic Compounds

COMPOUND	H atm*m ³ /mol
CHLORINATED COMPOUNDS	
CARBON TETRACHLORIDE	0.023
CHLOROBENZENE	0.0036
TETRACHLOROETHENE	0.0153
TRICHLOROETHENE	0.0091
AROMATICS	
BENZENE	0.0055
ETHYLBENZENE	0.0066
TOLUENE	0.0067
M-XYLENE	0.0070
O-XYLENE	0.0050
P-XYLENE	0.0071

Henry's Law Constants are at 20-25 °C.
Data from Pankow (1986).

The ratio of V_g/V_s for a given allowable % error at 20 °C can be calculated by the following equation:

$$\frac{V_g}{V_s} = \frac{(2.4E-02) (\%ERR)}{H(100 - \%ERR)}$$

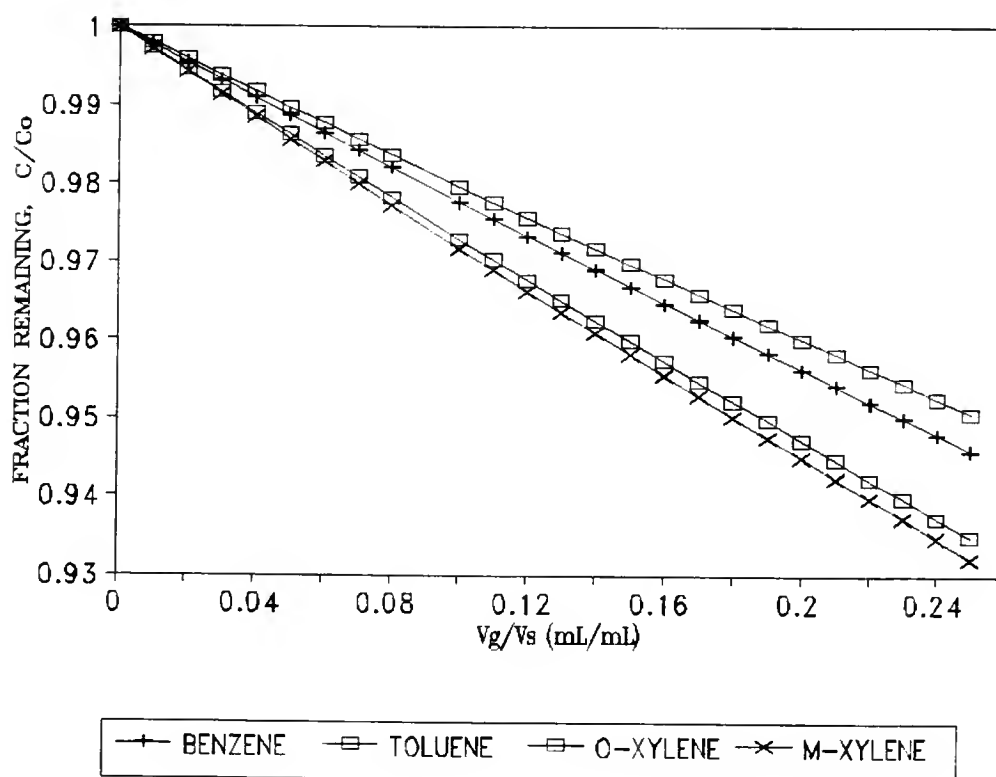


Figure G.1 Fraction Remaining C/C_0 versus V_g/V_s for Headspace Related Errors for Selected Aromatic Compounds. Compounds Apply to 20 °C.

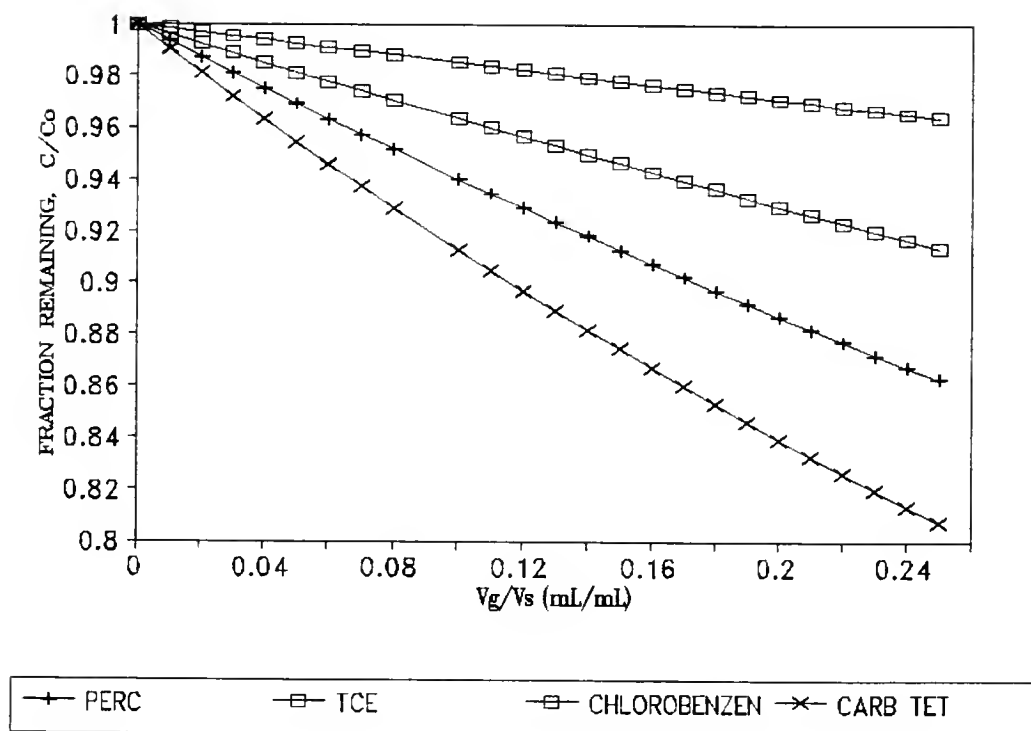


Figure G.2 Fraction Remaining C/C_0 versus V_g/V_s for Headspace Related Errors for Selected Chlorinated Compounds. Compounds Apply to 20 °C.

APPENDIX H OVERVIEW OF GROUNDWATER STRATEGIES

H.1 Groundwater Studies

H.1.1 Planning

Before any contamination assessment site work can be performed, it is imperative that an effective groundwater sampling protocol be developed. A protocol is a detailed list of step-by-step procedures that govern the entire groundwater study. The protocol is used to ensure quality assurance/quality control (QA/QC) in contamination studies. It normally includes the following:

1. Procedures for determining the soil stratigraphy along with the hydrogeological conditions such as the water table depth, the direction of flow, the hydraulic gradient, and possibly the conductivity of the aquifer.
2. Specific locations (up and down gradient of potential contaminant source) for groundwater sampling.
3. Drilling and construction methods for monitoring well installation, disposal of contaminated soil cuttings, and decontamination of equipment.
4. Construction materials to be used in the monitoring wells.

5. Equipment and procedures for well development and purging.

6. Devices to be used for sample collection, along with quality control procedures.

7. The size and number of samples (including equipment and trip blanks) to be taken and the chemical analysis to be performed on each.

8. Details on the preservation and transport of samples.

9. The chain of custody for samples.

Most regulatory agencies require a contamination assessment plan which outlines the protocol to be submitted and approved before any site work commences. Barcelona and Gibb (1988) give an excellent generalized groundwater sampling protocol. Barcelona et al. (1986) also wrote a practical guide for groundwater sampling for the EPA. Nacht (1983) also discusses factors to be considered when planning a groundwater monitoring system.

H.1.2 Conventional Sampling Mechanisms

Groundwater samplers are normally placed into one of three categories: grab, suction-lift, or positive displacement (Nielsen and Yeates, 1985). Figure H.1 (from Nielsen and Yeates, 1985) shows conventional sampling groundwater mechanisms. Grab samplers consist of bailers and syringes. Suction-lift devices include centrifugal and peristaltic pumps, while positive displacement samplers

consist of bladder pumps, submersible pumps, and gas-drive devices.

Sampling devices should be manufactured of inert materials to avoid reacting with the expected groundwater contaminants. The sampling device should not leach any contaminant nor should it adsorb contaminants from the groundwater. A good sampling device will not subject the sample to aeration or to large pressure changes. Studies by Barcelona and Wehrmann (1990) give the following order of preference of materials for groundwater sampling devices: Teflon (polytetrafluoroethylene), stainless steel 316, stainless steel 304, polyvinylchloride (PVC), low-carbon steel, galvanized steel, and carbon steel. Pettyjohn et al. (1981) propose an order of preference: glass, Teflon, stainless steel, polypropylene, and polyethylene.

Bailers are the simplest method of groundwater sampling and are normally composed of either Teflon, PVC, or stainless steel. Sampling is performed by attaching a nylon line to the bailer and then lowering it down the monitoring well. The bailer has a ball which is seated over a small hole in its bottom. When the bailer reaches the water table, the water unseats the ball from the hole and allows water to enter the bailer. When the bailer is pulled up, the ball then covers the hole, keeping the sample intact. At the surface, the sample is decanted from the bailer to glass bottles or vials.

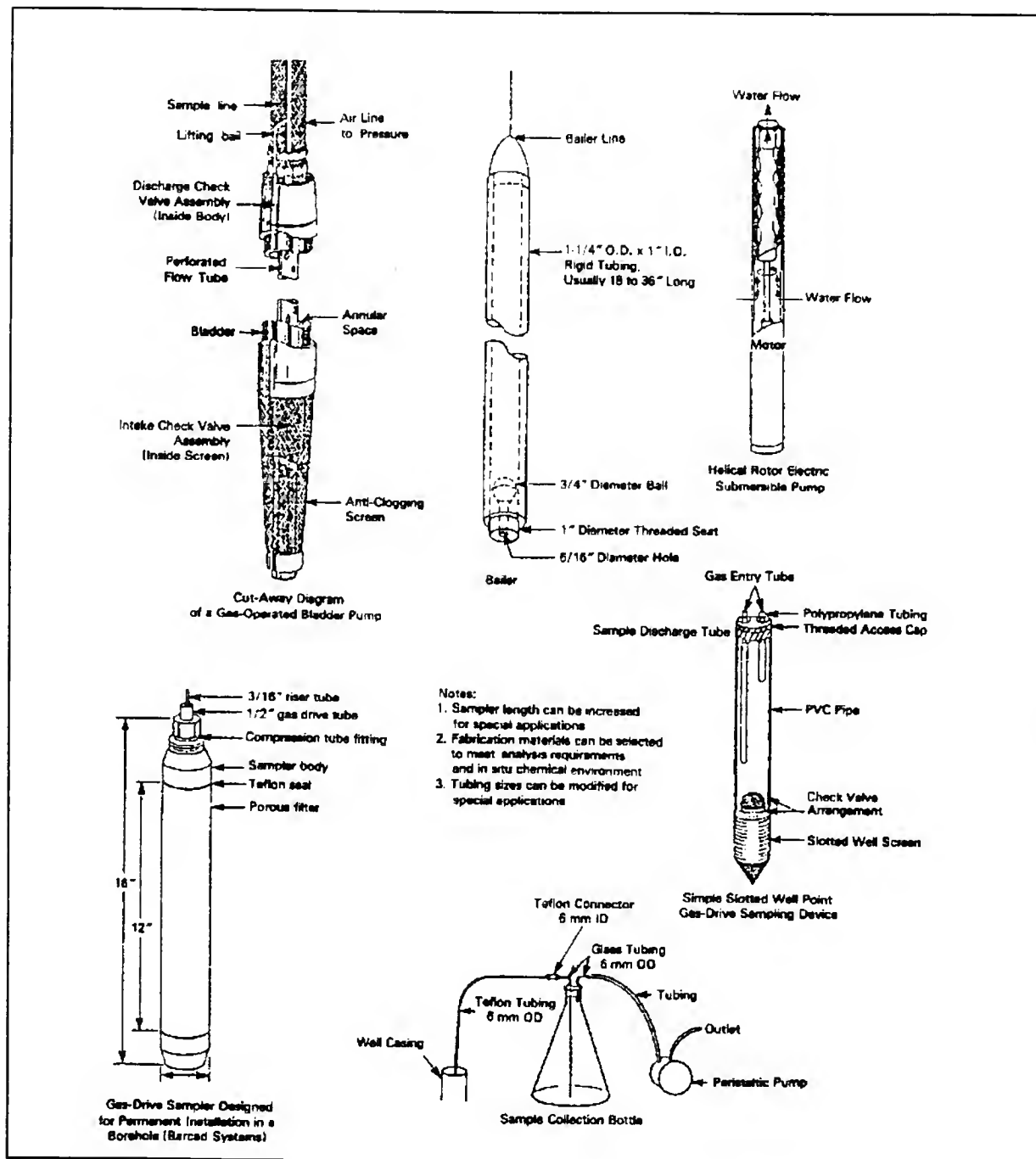


Figure H.1 Conventional Groundwater Sampling Mechanisms (Nielsen and Yates, 1985)

Syringe devices make use of medical type syringes from which the plunger handle and finger grips have been removed. Flexible tubing is attached to the syringe and at the other end to a hand pump. To obtain a sample a stainless steel ballast is placed on the device to allow the sampler to go to depths below the water table. At the desired sampling depth the hand pump is used at the ground surface to pull the plunger back and allow the sample to enter the device via a syringe needle. Gilliam (1982) discusses three syringe-sampling devices along with their advantages. The device is inexpensive, manually operated, and can be used to obtain samples at any depth. It has the disadvantage of only obtaining a small sample (50 mL).

Suction lift mechanisms are generally of two types: centrifugal and peristaltic. The devices are limited to pumping water a height of approximately 25 feet. Centrifugal pumps use a rotating impeller to discharge water by means of centrifugal force. Unfortunately, centrifugal pumps need to be primed and cause a significant amount of pressure change and turbulence, resulting in degassing and loss of VOCs. Peristaltic pumps make use of ball-bearing rollers, a rotor, and flexible Teflon tubing. The tubing is placed around a rotor, which is squeezed by ball-bearing rollers. These rollers rotate around the rotor, causing water to be pulled into the flexible tubing. One end of a length of tubing is lowered down the monitoring well into the water while the

other end is connected at the surface to an Erlenmeyer flask. The Erlenmeyer flask is connected by further tubing to the peristaltic pump. With this arrangement, water is drawn up the Teflon tubing and trapped in the Erlenmeyer flask and does not come into actual contact with the pump. Since pumps use negative pressures, degassing and VOC losses are prevalent.

Positive displacement mechanisms or gas-drive devices force positive pressure down tubing to a sampling chamber. The water sample is displaced up another tube to the surface where the water is collected. One simple device consists of a slotted well screen with a ball check-valve. At the ground surface, positive pressure (nitrogen gas) is applied to the device through a gas entry tube which closes the check-valve. The device is lowered to the sampling depth and the positive pressure decreased, allowing water to enter through the check valve. Once the chamber is filled with water, positive pressure is again added to close the check valve. The pressure is then increased to a value higher than the hydrostatic pressure at the sampler to displace water in the chamber through a discharge tube to the ground surface where it is collected. Since positive pressure is used instead of negative pressure, there is little possibility of degassing and loss of volatiles. These devices are relatively inexpensive and can be used at almost any depth. One manufacturer's device (BARCAD) can be installed in a bore hole and then backfilled, thus becoming a permanent monitoring

well. This allows the device to reach equilibrium with the aquifer, eliminating the need for purging before sampling. It is very difficult to determine whether these devices are properly installed and once installed they cannot be removed if repair is required. Robin et al. (1982) describe the use of two types of gas-drive sampling devices. The installation techniques and cost savings associated with this type of sampling is discussed by Barvenik and Cadwgan (1983).

Gas-operated bladder or diaphragm pumps operate on the same principle as the other positive displacement methods except that the gas does not come in contact with the sample. To obtain a sample, a positive pressure is applied, which closes a check-valve in the bottom of the device. The device is then lowered to the sampling depth and the pressure is released, allowing water to enter the bladder through the check valve. Once the bladder is filled, positive pressure is added to close the check-valve and to displace the water in the bladder by positive displacement into the discharge line to the surface. The process can be repeated for additional sampling. These samplers can be used to depths of approximately 200 feet. They are designed for sampling low contaminant levels. Bladder pumps are, however, relatively expensive.

Another class of sampling mechanism is the submersible pump, of which there are two types. The first is a helical-rotor electric submersible pump. This has an enclosed

electric motor which runs a helical rotor. Water is pushed up a discharge line to the surface by the centrifugal force produced by the rotor. The pump has a diameter of 1.75 inches and is 33 inches long. It has the capability of pumping to a depth of 125 feet. The pump is, however, relatively expensive and also the flow rate cannot be controlled. The second type is the gear-drive electric submersible pump. It uses an electric motor to run two Teflon gears, which push water up a discharge line to the surface. The pump is 1.75 inches in diameter and 7 inches long. It has a pumping rate of approximately 0.5 gpm.

A discrete point sampler for use in monitoring wells 2 inches or greater in diameter is discussed by MacPherson and Pankow (1988). This sampler allows groundwater samples to be taken which are not exposed to headspace in the sampling chamber. It also keeps the water at its insitu pressure.

Rannie and Nadon (1988) describe a pump sampling method that does not fall into any of the three normal categories of samplers. The pump is known as an inertial pump and is made of a foot valve and Teflon tubing. The foot valve is placed in the monitoring well at the desired sampling depth with the Teflon tubing running from it to the surface and into a glass bottle for sample collection. As the device is lowered in the monitoring well, water enters the foot valve and rises into the tube to the hydrostatic level. To sample, the tubing is pulled upward and downward in a rhythmic fashion by use of

either a levered handle at the surface or a gas driven motor. When the tubing is pulled upward, the foot valve closes and the water in the tube rises a distance equal to the length of the stroke applied. By pushing the tube downward, the foot valve opens and allows more water to enter the tubing. Constant, rapid motion pumps water to the surface where it is collected. The greater the depth to be sampled, the more rapid the stroke rate must be. The manual pump rate can vary from 1 to 7 liters per minute. In a 1.5 inch diameter well, the maximum lift is about 50 meters. As the size of the well increases, the maximum lift decreases due to swaying of the tube which makes the process less efficient. This mechanism can also be used for well development by overpumping, purging of monitoring wells, and for performing hydraulic conductivity tests for soil with conductivities in the range of 10^{-6} to 10^{-4} m/sec.

Johnson et al. (1987) describe a groundwater sampler that can be used in wells with an inner diameter greater than 1 cm. The sampler is lowered down the well and water enters through a bottom check valve into a sample reservoir. The device has an overfill section for water which is exposed to headspace. When the device is pulled up from the monitoring well, the check valve ensures no loss of sample. At the surface, sections are crimped on either side of the sample reservoir to seal the sample. The sample is thus stored in the device for transport to a lab. Decreased handling, reduces VOC loss.

Pohlmann and Hess (1988) published a matrix of twelve different sampling devices with information on their applicability to obtain representative samples for several different groundwater parameters, including VOCs, pH, electrical conductivity (EC), total organic carbon (TOC), trace metals, and non-volatiles. It also gives operational information, including the minimum well diameter required, maximum depth of sampling, and sample delivery rates.

H.2 Monitoring Well Design Considerations

H.2.1 General

At the start of any groundwater monitoring program there are a number of questions which must be answered to facilitate the proper design of monitoring wells. Some of these questions are:

1. What size of monitoring well is required?
2. What are the expected contaminants?
3. What are the soil stratigraphy and hydrogeological data?
4. What construction materials should be used?

H.2.2 Monitoring Well Size

Many regulatory agencies require a minimum inner diameter of 2 inches for monitoring wells. If the monitoring well is also to be used for hydraulic conductivity testing, a larger well will be required. A smaller diameter well will

lower the costs of drilling and will also decrease the volume of stagnant water that has to be purged before sampling.

Normally wells should be of a length to penetrate the first permeable downgradient water bearing unit. The more complex the geology, the more wells are required at a site.

H.2.3 Expected Contaminants

The contaminants must be known to select properly the materials for well construction in order to avoid possible chemical reactivity. Some contaminants may interact with the bentonite seal causing other compounds to leach out of the bentonite. Some contaminants are less dense than water, while others, such as trichloroethylene, chloroform, and perchloroethylene, are denser. Dense solvents will sink until they reach a confining stratum. This can affect the depth required for the monitoring well.

H.2.4 Water Table Depth

It is standard practice to have a screened interval of at least two feet above the water table to allow for fluctuation in ground water levels. If the well screen does not intersect the water table, contaminants that are lighter than water and float on the water table would not be detected in the monitoring wells.

H.2.5 Screen and Casing Materials

Normally, Teflon or stainless steel screens are used in monitoring wells since they are relatively inert. PVC may be used for the well casing with Teflon for the screened interval. This can cut down on material costs. It is best not to join materials by using glues or solvents, which could leach into the well and contaminate it. Threaded materials which provide a flush joint are more acceptable. Dablow et al. (1988) have suggested the following for the design and installation of monitoring wells when using Teflon. Due to the strength of the male-female threaded joints of Teflon screens, they should only be used to a depth of 107 meters. The screen size may have to be increased by up to 25% to allow for compression of the slots which occurs when they are under compressive load. To ensure the well is vertical, centralizers (spacers) spaced every 1.5 meters should be placed around the well to keep it centered in the borehole. Another more suitable technique to ensure verticality is the use of a rigid PVC pipe inside the well screen/casing. This method is known as the insertion method. It consists of placing a rigid PVC pipe of smaller outer diameter than the inner diameter of the well casing/screen into the well casing just before insertion into the borehole. Once in the borehole it remains in place until backfilling is complete. If the well is not vertical, obtaining samples from several different

mechanisms, such as bladder pumps or bailers, may not be possible.

Jones and Miller (1988) discuss the adsorption of some organic chemical contaminants onto different well casing materials. They used well casings of PVC, three types of Teflon (TFE-tetrafluoroethylene, PFA-perfluoroalkoxy, and FEP-fluorinated ethylene propylene), stainless steel, and Kynar (PVDF-polyvinylidene fluoride). They concluded that leaching of adsorbed contaminants from these well casing materials did not occur to any large extent. Sample representativeness was more highly dependent upon well purging. Sorption of contaminants onto well casing materials was a function of its water solubility. The lower the water solubility of the contaminant, the larger the amount of sorption that would occur on the well casing. The polarity of the contaminant also affected sorption. Polar contaminants did not sorb as readily as less polar ones. This is due to the polar nature of water. Polar materials such as water tend to prefer other polar materials. Xylenes, toluene, and other benzene derivatives are normally nonpolar.

PVC can be used for monitoring wells when organic contamination is not expected. In the presence of organics, PVC not only leaches but also loses considerable strength. Nielsen (1988) believes that PVC can be used even for the analysis of organic contaminants. He contends that before a sample is taken from a monitoring well it is purged of

stagnant water, thereby bringing representative aquifer water into the well. This representative water is sampled just after well purging so that the water does not have sufficient time to react significantly with the well casing or screen.

A steel casing should be placed around the well casing at the ground surface to serve as a well protector. This prevents vandalism to the monitoring well and possible damage from vehicles. The well protector should be placed in concrete and should project approximately 3 feet above the ground surface. This makes it more visible to grass mowers. This protector need only be installed a few feet into the concrete cap.

Voytek (1983) and Riggs and Hatheway (1988) offer excellent overviews of monitoring well construction and use. Details on drilling methods for monitoring wells installation are provided by Keely and Boateng (1987) and by Hackett (1988). Decontamination of drilling equipment is discussed by Mickam et al. (1989). Chapter 5 of EPA's Handbook: Groundwater (USEPA, 1987) is an excellent reference for monitoring well design and construction. Excellent textbooks on well design include Water-Well Design and Construction (Harlan et al., 1989), Handbook of Groundwater Development (Roscoe Moss Company, 1990), and Practical Handbook of Ground-Water Monitoring (Nielsen, 1991).

H.3 Well Development

After a well is installed, it must be developed for proper use. When a well is installed using drilling muds, fine particles can cake on the sides of the borehole and may reduce the permeability and inhibit the flow of water into the screened interval of the well. These particles are removed by alternately moving water at high velocity in and out of the well screen. This can be accomplished with the use of a surge block or plunger. When the plunger is pushed down, water is forced through the well screen into the aquifer formation. When the plunger is pulled up it produces a suction which pulls water from the formation along with fine particles. The particles will settle out in the bottom of the monitoring well and can be pumped out. If wells are not properly developed, samples obtained may contain large amounts of suspended solids. Using a surge block for well development can cause the filter pack around the well screen to be driven into the formation if excessive force is used.

Many engineers prefer to develop wells by overpumping. This consists of pumping the monitoring well almost completely dry. This can be accomplished with bailers in low permeability soils but will require a pump which can operate at a fast rate in high permeability soils. After the well is pumped dry it is normally allowed to recover and then it is overpumped again. After two repetitions the water normally is sufficiently clear, indicating that the well is developed.

Air development is yet another possible method for well development. Using a jet device, compressed air can be forced through the well screen to develop the well. This method can, however, expose workers at the surface to hazardous vapors as the compressed air can cause contaminants to volatilize.

H.4 Purging of Wells

Before sampling, monitoring wells must be purged of their existing water, since the water in the monitoring well is not representative of the actual insitu conditions. It is stagnant and has been allowed to react with the well screen and casing for a considerable amount of time. It has also been allowed to interact with the atmosphere, causing loss of some contaminants. If a well is capped, there is still a significant amount of headspace in the well, which could cause loss of VOCs. Contaminants may have leached from the well materials into the water or contaminants may have sorbed onto the well materials.

There is considerable debate over how stagnant water should be purged from wells. Most regulatory agencies suggest removing a certain number of well volumes, typically in the range from 3 to 10. An important consideration in the purging of the stagnant water is the rate at which it is removed. Purging is best accomplished at slow rates on the order of 100 mL per minute. However, at slow rates it may take a considerable amount of time to purge a well. If rates are too

fast and volumes too large, high concentrations of contaminants may be brought to the well artificially by the pumping action. Others suggest that purging be done while monitoring pH, redox potential (Eh), specific conductance, and temperature. Once values stabilize within 10%, sampling can begin. For shallow depths, bailers are normally used to purge the wells. Submersible pumps or bladder pumps may be used to purge deep wells.

Keely and Boateng (1987) contend that only the water in the casing above the screened section needs to be purged. Since the well screens are very permeable, the natural groundwater flow will purge the screen. Water will continually be moving in and out of the screened section. In some rare instances where almost no flow occurs the screened area will have to be purged also.

H.5 Sampling Studies

H.5.1 Lab Studies

Several laboratory studies have been performed to evaluate the effectiveness of particular groundwater sampling mechanisms for obtaining reliable and repeatable representative samples. Ho (1983) looked at the effect of several different variables on the recovery of volatile organics using a peristaltic pump. He found PTFE (polytetrafluoroethylene) tubing was needed since contaminants sorbed onto standard tubing. He also found a decrease in the recovery of organics occurred as the pumping

rate increased. The initial concentration of the contaminants also played a major role. Samples containing low initial concentrations of VOCs had a small recovery. He also found that the higher the lift of the sample, the lower the VOC recovery. This was due to the organics being volatilized and lost in the sampling line by the vacuum. Ho also evaluated the effect that headspace and temperature had on the concentrations of VOCs. He looked at nine compounds in samples at three different temperatures (30°C, 24°C, and 4°C) at 24 and 48 hours. Higher temperatures resulted in a greater loss of VOCs. He found that partially filled bottles could be stored at 4°C for two days without significant loss of volatiles (<10%).

Barcelona et al. (1984) performed a laboratory study to evaluate the effectiveness of 14 sampling mechanisms using a pvc standpipe. First the sampling mechanisms were evaluated based upon such factors as availability, portability, sampling rate, purging rate, range of operation, volatile compounds, and adequacy of manufacturer's operation instructions. Then they were evaluated based upon their ability to evaluate the chemical parameters of pH, total dissolved solids (TDS), TOC, alkalinity, hardness, and ionic strength. Finally, samples were taken to evaluate the recovery and precision of purgeable organic compounds. The study ranked the bladder (no-gas contact) pump as superior to the other methods, followed by grab samplers (conventional bailer, dual check valve bailer,

and syringe pump), positive displacement (mechanical), gas displacement, and suction (peristaltic pump) methods. The peristaltic pump and gas displacement methods were not recommended for ground water sampling of VOCs. Performance of grab samplers such as bailers was found to be very dependent on the ability of the operator. Barcelona et al. (1984) suggested that a sampling rate of less than 100 mL per minute would minimize degassing of VOCs.

Tai et al. (1991) performed a laboratory study using a 100 feet high stainless steel standpipe in order to evaluate the effectiveness of certain sampling devices for the retention of VOCs. The standpipe had 14 ports where samples could be taken simultaneously with the different sampling devices. Five chlorinated volatile organic chemicals were used in the standpipe. Non-pumping and pumping samplers were used. Among the non-pumping samplers the highest recovery of organics was obtained by the manual-driven piston sampler, followed by the motor-driven piston sampler and finally by the bailer. A flow controlled bottom emptying device was used for the bailer.

Unwin and Maltby (1988) used a 55-gallon drum filled with spiked distilled water to evaluate four samplers. A floating cover was placed over the liquid to reduce loss of VOCs. A two inch diameter well casing was placed through the floating cover to simulate a monitoring well. The compounds used in the study were diethylether, chloroform, toluene,

trichloroethylene, and tetrachloroethylene. These compounds cover a wide range of the Henry's Law Constant (H) which is a measure of volatility. A compound with a large H value will more readily leave the water phase and go into a gaseous phase. Results of the testing showed the peristaltic pump to have the highest loss of volatiles, followed by the submersible pump, the bailer, and finally the bladder pump. The testing also showed that as Henry's Constant increased so did the loss of the volatiles.

Work done by Barker et al. (1987) showed that organic solutes can penetrate teflon tubing and can contaminate water samples being drawn to the surface causing false positives. They found that BTX (benzene, toluene, and the xylenes) would be sorbed by teflon tubing and could subsequently leach off giving false positives.

Four sampling devices were tested with three chlorinated hydrocarbons by Schalla et al. (1988) to evaluate the sensitivity of these devices in sampling VOCs. The devices used were a stainless steel and Teflon piston pump, a Teflon bailer, a Teflon bladder pump, and a pvc airlift pump. They found no significant statistical difference in the accuracy and precision of these sampling devices, meaning all the samplers studied, recovered VOCs equally as well.

H.5.2 Field Studies

Imbrigiotta et al. (1988) performed a field evaluation of seven different sampling devices at three different sites. The seven samplers used were a bladder pump, helical-rotor submersible pump, gear submersible pump, bailer, point-source bailer, syringe sampler, and peristaltic pump. The first site studied was in Cape Cod, Massachusetts. The results showed the bladder pump, open bailer, and helical-rotor submersible pump consistently recovered the highest concentrations of volatiles while the peristaltic pump recovered the lowest. At a northern New Jersey site, the point-source bailer and the gear submersible pump were the most effective with the peristaltic pump the least effective. The bladder pump surprisingly performed just slightly better than the peristaltic pump at this site. This was believed to have been the result of operational problems. The third site in southern New Jersey produced surprising results. At this site, the peristaltic pump was slightly more effective than the other methods. The bladder pump, point-source bailer, open bailer, and the gear submersible pump all were in the 95% confidence level. Temperature was thought to have played a major factor in the performance of the peristaltic pump. Sampling at the northern New Jersey site was performed in August and heating of the discharge line could have caused degassing of the volatiles while the sampling at the southern New Jersey site occurred in December when it was cloudy. The

authors also showed that the pumping rate used to purge a well can have significant effects on the recovery of volatiles. They showed that using a high pumping rate caused higher concentrations to be pulled into the well than using a smaller pumping rate. It is possible for higher pumping rates to decrease the concentrations by pulling in a larger amount of less-contaminated ground water. Ficken (1988) also discusses a manual piston sampler and an electric gear pump sampler that the U.S. Geological Survey is developing.

Low permeability soils can also affect losses of VOCs. McAlary and Barker (1987) observed this when a monitoring well is purged dry. In such a situation water will cascade through the headspace which is in the sand filter around the monitoring well. This causes the water to be exposed to the atmosphere and will result in a loss of volatiles.

Field tests were performed at Long Island, New York, in 1983 to evaluate seven samplers (three submersible pumps, one centrifugal pump, 2 peristaltic pumps, and one bailer). Pearsall and Eckhardt (1987) made use of 6 inch diameter wells to allow simultaneous sampling. Intakes of all the sampling pumps were placed closely together at the same depth in the monitoring well and all pumps were started at the same time in order to accomplish simultaneous sampling. They found, contrary to most researchers, that the peristaltic pump did not significantly lower the VOC concentrations. It was also observed that pumping a specified number of well volumes from

the monitoring wells did not ensure stable VOC concentrations in the wells.

Barker and Dickhout (1988) evaluated three sampling mechanisms for VOCs. The mechanisms used were a bladder pump (Well Wizard), a peristaltic pump, and an inertial pump. Field and lab evaluations were performed. The field testing was performed in North Bay, Canada. A six inch diameter monitoring well was used to allow the three sampling mechanisms to be used for simultaneous sampling. The bladder pump and the inertial pump gave comparable concentrations for the volatile aromatic hydrocarbons with the exception of benzene. The inertial pump gave benzene values that were 7% lower. The peristaltic pump gave considerably lower values for all compounds than the other two mechanisms. In lab testing the inertial pump gave the highest concentrations followed by the bladder pump and then the peristaltic pump.

Barcelona and Helfrich (1986) looked at the effect of well construction and purging procedures on ground water samples. They made use of 2 inch inner diameter monitoring wells at a municipal landfill. At site one, three monitoring wells were installed within 2 meters of each other. The three wells were constructed of teflon (PTFE), stainless steel (SS), and polyvinyl chloride (PVC). At site two, the wells consisted of PVC, SS, and a BARCAD insitu sampler with teflon tubing. All the wells were sampled with a bladder pump (Well Wizard). There were significantly different values of

contamination in the PVC monitoring wells than in the teflon and stainless steel wells. In one instance leaching of iron from the stainless steel was also apparent. The authors concluded that improper well purging can cause more bias in results than the material effect or sampling mechanism.

H.6 Underground Storage Tank Regulatory Programs

H.6.1 Congressional Acts

The Resource Conservation and Recovery Act of 1976 covers the proper management of hazardous and nonhazardous solid wastes (USEPA, 1990). The act covers four programs: Subtitle D governs the solid waste program, Subtitle C governs the hazardous waste program, Subtitle I governs the underground storage tank program, and Subtitle J governs the medical waste program. The underground storage tank program is meant to prevent leakage from tanks and to clean up sites where leakage has occurred. In 1980 the Comprehensive, Environmental Response, Compensation and Liability Act (CERCLA), also known as Superfund, was passed. Superfund set up a fund for the investigation and remedy of abandoned uncontrolled hazardous waste sites. The act made it possible to come up with a list of abandoned hazardous waste sites and potential responsible parties. The Hazardous and Solid Waste Amendments (HSWA) which were passed in November 1984 directed the Environmental Protection Agency (EPA) under Subtitle I to develop standards

for the design, construction, and installation of new tanks along with requirements for owners regarding record keeping, leak detection and reporting, corrective action, and closure. On September 23, 1988, these standards were issued by the EPA. The Superfund Amendments and Reauthorization Act of 1986 (SARA) gave the EPA the authority to clean up releases from underground storage tanks or to direct owners to clean up their sites. This act also set up a trust fund to cover the cleanup cost when it exceeded the coverage requirements of the responsible party.

H.6.2 EPA's Underground Storage Tank Program

The Resource Conservation and Recovery Act defined an underground tank as one in which at least 10% of its volume, including piping, was underground. Tanks that were exempt from this program included farm and residential tanks holding 1100 gallons or less, tanks for heating oil that would be used where they were stored, and septic tanks.

There are four major causes of leaks from underground tanks. They are as follows:

1. Corrosion of tanks.
2. Poor installation, usually associated with loose fittings on pipes.
3. Settlement causing pipe ruptures.
4. Overfilling of tanks.

USEPA (1986) described what it considered to be the essential parts of a ground water monitoring program under RCRA. The areas included:

1. Characterization of site hydrogeology.
2. Location and number of ground water monitoring wells.
3. Design, construction and development of ground-water monitoring wells.
4. Content and implementation of the sampling and analysis plan.
5. Statistical analysis of ground water monitoring data.
6. The content and implementation of the assessment plan.

Under the RCRA Ground-Water Monitoring Technical Enforcement Guidance Document (1986) the EPA required a minimum of 4 monitoring wells (three downgradient and one upgradient). It is highly suggested that monitoring wells be put along the perimeter of an underground storage tank to detect a leak in its initial stages. Normally more than one upgradient well is required to give background water quality data. For new underground storage tanks, the EPA requires a written ground water sampling and analysis plan which spells out sample collection procedures, sample preservation, and chain of custody. This document is used by regulatory personnel to see if an owner/operator is following his plan. Other special items include the use of stainless steel wells when looking for volatile organic compounds over a 30 year period, since they have more structural integrity.

The HSWA Amendments to RCRA (Bellandi, 1988) provided for the following:

1. Registration of new and existing tanks with state and local agencies. Owners of existing tanks had until May 1986 to register their tanks. All tanks installed after May 8, 1986, also had to be registered (EPA form 7530-1).

2. Standards for new underground tanks to prevent releases. Tanks are to be constructed of material compatible with the product to be stored and steel tanks are to be cathodically protected. All existing underground storage tanks must meet the standard for new tanks by December 22, 1998. Existing underground tanks containing petroleum or hazardous waste must install a release detection system by December 22, 1993.

3. Under Subtitle J, all new underground tanks for the storage of hazardous waste are required to have a secondary containment system. The purpose of this system is to contain a leak should the tank fail. The containment system must be compatible with the material to be stored and must have a leak detection system. The tank must have a base or foundation to resist settlement. The secondary containment system must have the capacity to contain 110% of the volume of the tank. The secondary containment system must be constructed to avoid infiltration. All existing underground tanks storing hazardous material must install a secondary containment system

by December 22, 1993, or be replaced with a double-walled tank.

Modern tank design requires leak detection by monitoring wells or between doubled walled tanks. Tanks must be corrosion resistant. Tanks should be constructed of either steel which is cathodically protected or non-metallic fiberglass. Double walled tanks are actually a tank within a tank with a vacuum in between. The pressure is monitored between the tanks in order to detect a leak. If a leak occurs a pressure change will occur in the vacuumed space between the tanks.

H.6.3 Florida DER Programs

The Florida Department of Environmental Regulation (FDER) has been a leader in the regulation of underground storage tanks. Chapter 17-61 of the rules of the FDER (1984) governs storage tanks in the state of Florida. This chapter mandated that by 1989 all underground storage tanks have a monitoring system in place for the detection of leaks, and for installation of overfill protection devices. It covers minimum requirements for monitoring wells. Schedule 40 PVC is an acceptable material for monitoring well construction. This chapter requires monitoring wells to be sampled at least once monthly if that is the detection system used. It also requires periodic testing of cathodically protected steel tanks.

Chapter 17-63 (FDER, 1984) governs local tank regulation programs. This chapter allows county or municipal tank ordinances provided they are approved by FDER. Normally this is done when the local ordinance is even more stringent than the State's program.

Requirements for monitoring and contamination assessment once a tank is known to have leaked are covered by Chapter 17-70 (FDER, 1984). It lists the appropriate EPA method that is to be performed for the chemical analysis of different contaminants. Target concentration levels of contaminants are listed which must be met to successfully remediate a contaminated site. For underground storage tanks, benzene must be less than 1 part per billion (ppb) and the total volatile organic aromatics must be less than 50 ppb.

REFERENCE LIST

Acar, Yalcin B. and Haider, Laique (1990), "Transport of Low Concentration Contaminants in Saturated Earthen Barriers," Journal of Geotechnical Engineering, ASCE, Vol. 116 No. 7, New York, pages 1031-1052.

Ballestro, Thomas, Herzog, Beverly, Evans, O.D., and Thompson, Glenn, (1991), "Monitoring and Sampling the Vadose Zone," Practical Handbook of Ground-Water Monitoring, David M. Nielsen, editor, Lewis Publishers, Chelsea, Michigan, pages 97-141.

Barcelona, Michael J. and Gibb, James P. (1988), "Development of Effective Ground-Water Sampling Protocols," Ground-Water Contamination: Field Methods, ASTM, 1988, Philadelphia, pages 17-26.

Barcelona, Michael J., Gibb, James P., Helfrich, John A., and Garske, Edward E. (1986), Practical Guide for Ground Water Sampling, EPA/600/s2-85/104, Feb. 1986.

Barcelona, Michael J., and Helfrich, John A. (1986), "Well Construction and Purging Effects on Ground Water Samples," Environmental Science and Technology, November, 1986, American Chemical Society, Washington, D.C., pages 1179-1184.

Barcelona, M.J., Helfrich, J.A., Garske, E.E., and Gibb, J.P. (1984), "A Laboratory Evaluation of Ground Water Sampling Mechanisms," Ground Water Monitoring Review, Spring 1984, pages 32-41.

Barcelona, Michael and Wehrmann, Allen (1990), Contamination of Ground Water: Prevention, Assessment, Restoration, Pollution Technology Review #184, 1990.

Barker, J.F. and Dickhout, R. (1988), "An Evaluation of Some Systems for Sampling Gas-Charged Ground Water for Volatile Organic Analysis," Ground Water Monitoring Review, Fall 1988, pages 112-120.

Barker, J.F., Patrick, G.C., Lemon, L., and Travis, G.M. (1987), "Some Bias in Sampling Multilevel Piezometers," Ground Water Monitoring Review, Spring 1987, pages 48-54.

Barvenik, Matthew J. and Cadwgan, Richard M. (1983), "Multilevel Gas-Drive Sampling of Deep Fractured Rock Aquifers in Virginia," Ground Water Monitoring Review, Fall 1983, pages 34-40.

Bellandi, Robert (1988), Hazardous Waste Site Remediation: The Engineer's Perspective, O'Brien & Gere Engineers, Inc., Van Nostrand Reinhold, New York, New York, 1988.

Blegen, Ronald P., Hess, John W., and Denne, Jane E. (1988), "Field Comparison of Ground-Water Sampling Devices," NWWA Second Annual Outdoor Action Conference in Las Vegas, May, 1988.

Cedergren, Harry R. (1977), Seepage, Drainage, and Flow Nets, 2nd edition, John Wiley and Sons, Inc., New York, New York, pages 26-85.

Clesceri, Lenore S., Greenberg, Arnold E. and Trussell, R. Rhodes (1989), Standard Methods for the Examination of Water and Wastewater, 17th edition, 1989, APHA, AWWA, and WPCF, Baltimore, Maryland.

Cooper, Stafford S. and Malone, Philip G. (1991), "Three-Dimensional Mapping of Contaminant Distribution in Soil Using a Soil Penetrometer," The Military Engineer, Society of American Military Engineers, August 1991, pages 54-55.

Dablow, John F., Persico, Daniel, and Walker, Grayson R. (1988), "Design Considerations and Installation Techniques for Monitoring Wells Cased with Teflon PTFE," Ground-Water Contamination: Field Methods, ASTM, 1988, Philadelphia, Pa., pages 199-205.

Edge, Russel W. and Cordry, Kent (1989), "The Hydropunch: An In Situ Sampling Tool for Collecting Ground Water from Unconsolidated Sediments," Ground Water Monitoring Review, Summer 1989, pages 177-183.

Ficken, James H. (1988), "Recent Development of Downhole Water Samplers for Trace Organics," Ground-Water Contamination: Field Methods, ASTM, 1988, Philadelphia, pages 253-257.

Florida Department of Environmental Regulation (1984a), Chapter 17-61, Stationary Tanks, Tallahassee, 1984.

Florida Department of Environmental Regulation (1984b), Chapter 17-63, Local Tank Regulation Programs, Tallahassee, 1984.

Florida Department of Environmental Regulation (1988), Chapter 17-70, State Underground Petroleum Environmental Response, Tallahassee, 1988.

Geomatrix Consultants (1986), Status of Field Studies for the 1990 Bay Road Site and Vicinity, East Palo Alto, California, Project 1057A, May 1986.

Gilliam, Robert W. (1982), "Syringe Devices for Ground-Water Sampling," Ground Water Monitoring Review, Spring 1982, pages 36-39.

Hackett, Glen (1988), "Drilling and Constructing Monitoring Wells with Hollow-Stem Augers - Part 2: Monitoring Well Installation," Ground Water Monitoring Review, Winter 1988, pages 60-68.

Haldorsen, Sylvi, Petsonk, Andrew M., and Torstensson, Bengt-Arne (1985), "An Instrument for In Situ Monitoring of Water Quality and Movement in the Vadose Zone," NWWA Conference on Characterization and Monitoring of the Vadose Zone, Denver, Colorado, November 19-21, 1985.

Harlan, R.L., Kolm, K.E., and Gutentag, E.D. (1989), Water-Well Design and Construction, Elsevier, New York, New York, 1989.

Ho, James S. (1983), "Effect of Sampling Variables on Recovery of Volatile Organics in Water," American Water Works Association Journal, November, 1983, Vol. 75, No. 11, pages 583-589.

Imbrigiotta, Thomas E., Gibbs, Jacob, Fusillo, Thomas V., Kish, George R. and Hochreiter, Joseph J. (1988), "Field Evaluation of Seven Sampling Devices for Purgeable Organic Compounds in Ground Water," Ground-Water Contamination: Field Methods, ASTM, 1988, Philadelphia, Pa., pages 258-273.

Johnson, Richard L., Pankow, James F., and Cherry, John A. (1987), "Design of a Ground-Water Sampler for Collecting Volatile Organics and Dissolved Gases in Small-Diameter Wells," Ground Water, July-August, 1987, NWWA, pages 448-454.

Joint Departments of the Army, the Air Force, and the Navy, USA (1983), Technical Manual TM 5-818-5/AFM 88-5, Chap 6/NAVFAC P-418, Dewatering and Groundwater Control, November 1983, page 4-24.

Jones, Jerry N. and Miller, Gary D. (1988), "Adsorption of Selected Organic Contaminants onto Possible Well Casing Materials," Ground-Water Contamination: Field Methods, ASTM, 1988, Philadelphia, Pa., pages 185-198.

Keely, Joseph F. and Boateng, Kwasi (1987), "Monitoring Well Installation, Purging, and Sampling Techniques - Part I: Conceptualizations," Ground Water, May-June 1987.

Klopp, Rick A., Petsonk, Andrew M, and Torstensson, Bengt-Arne (1989), "In-situ Penetration Testing for Delineation of Ground Water Contaminant," Proceedings of the Third National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods, May 22-25, 1989, Orlando, Florida, National Water Well Association, Dublin, Ohio, pages 329-342.

Lammons, Thomas L., Mann, Thomas A. and Pelletier, A. Michel (1991), "An Assessment Tool for Sampling Ground Water in the Undisturbed Saturated Zone," report by Sirrine Environmental Consultants, Greenville, South Carolina.

MacPherson, James R. and Pankow, James F. (1988), "A Discrete Point Sampler for Ground Water Monitoring Wells," Ground Water Monitoring Review, Summer 1988, pages 161-164.

McAlary, T.A. and Barker, J.F. (1987), "Volatilization Losses of Organics During Ground Water Sampling for Low Permeability Materials," Ground Water Monitoring Review, Fall 1987, pages 63-74.

Mickam, James T., Bellandi, Robert, and Tift, Edwin C. (1989), "Equipment Decontamination Procedures for Ground Water and Vadose Zone Monitoring Programs: Status and Prospects," Ground Water Monitoring Review, Spring 1989, pages 100-121.

Nacht, Steve J. (1983), "Ground-Water Monitoring System Considerations," Ground Water Monitoring Review, Spring 1983, pages 33-39.

Nielsen, David M. (1988), "Much Ado about Nothing: The Monitoring Well Construction Materials Controversy," Ground Water Monitoring Review, Winter 1988, pages 4-5.

Nielsen, David M. (1991), Practical Handbook of Ground-Water Monitoring, Lewis Publishers, Inc., Chelsea, Michigan, 1991.

Nielsen, David M., and Yeates, Gillian L. (1985), "A Comparison of Sampling Mechanisms Available for Small-Diameter Ground Water Monitoring Wells," Ground Water Monitoring Review, Spring 1985, pages 83-99.

Pankow, James F. (1986), "Magnitude of Artifacts Caused by Bubbles and Headspace in the Determination of Volatile Compounds in Water," Analytical Chemistry, Vol. 58, July, 1986, American Chemical Society, Washington, D.C., pages 1822-1826.

Pearsall, K.A. and Eckhardt, D.A. (1987), "Effects of Selected Sampling Equipment and Procedures on the Concentrations of Trichlorethylene and Related Compounds in Ground Water Samples," Ground Water Monitoring Review, Spring 1987, pages 64-73.

Petsonk, Andrew M. (1985), "A Device for In Situ Measurement of Hydraulic Conductivity," AGU Symposium on Advances in Hydraulic Testing and Tracer Methods, San Francisco, California, December 10, 1985.

Pettyjohn, Wayne A., Dunlap, W.J., Cosby, Roger, and Keeley, Jack W. (1981), "Sampling Ground Water for Organic Contaminants," Ground Water, March-April, 1981, NWWA, pages 180-189.

Pohlmann, K.F. and Hess, J.W. (1988), "Generalized Ground Water Sampling Device Matrix," Ground Water Monitoring Review, Fall 1988, pages 82-84.

Rannie, E.H. and Nadon, R.L. (1988), "An Inexpensive, Multi-Use, Dedicated Pump for Ground Water Monitoring Wells," Ground Water Monitoring Review, Fall 1988, pages 100-107.

Riggs, Charles O. and Hatheway, Allen W. (1988), "Ground-Water Monitoring Field Practice--An Overview," Ground-Water Contamination: Field Methods, ASTM, 1988, Philadelphia, Pa., pages 121-136.

Robin, Michel J.L., Dytyynyshyn, David J., and Sweeney, Stewart J. (1982), "Two Gas-Drive Sampling Devices," Ground Water Monitoring Review, Winter 1982, pages 63-66.

Roscoe Moss Company (1990), Handbook of Ground Water Development, John Wiley and Sons Inc., New York, New York, 1990.

Schalla, Ronald, Myers, David A., Simmons, Mary Ann, Thomas, John M., and Toste, Antony P. (1988), "The Sensitivity of Four Monitoring Well Sampling Systems to Low Concentrations of Three Volatile Organics," Ground Water Monitoring Review, Summer 1988, pages 90-96.

Shackelford, Charles D. and Daniel, David E. (1991a), "Diffusion in Saturated Soil - Part I: Background," Journal of Geotechnical Engineering, ASCE, March 1991, pages 467-484.

Shackelford, Charles D. and Daniel, David E. (1991b), "Diffusion in Saturated Soil - Part II: Results for Compacted Clay," Journal of Geotechnical Engineering, ASCE, March 1991, pages 485-506.

Smolley, Mark and Kappmeyer, Janet C. (1991), "Cone Penetrometer Tests and Hydropunch Sampling: A Screening Technique for Plume Definition," Ground Water Monitoring Review, Spring 1991, pages 101-106.

Strutynsky, Andrew I., and Sainey, Timothy J. (1990), "Use of Piezometric Cone Penetration Testing and Penetrometer Groundwater Sampling for Volatile Organic Contaminant Plume Detection," Proceedings of Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Restoration, October 31 - November 2, 1990, Houston, Texas, Ground Water Management, NWWA.

Stuart, S. (1986), Environmental News, Vol.8, No. 4, Florida Department of Environmental Regulation, 1986.

Tai, Doreen Y., Turner, Kenneth S. and Garcia, Lisa A. (1991), "The Use of a Standpipe to Evaluate Ground Water Samplers," Ground Water Monitoring Review, Winter 1991, pages 125-132.

Torstensson, Bengt-Arne (1984), "A New System for Ground Water Monitoring," Ground Water Monitoring Review, Fall 1984, pages 131-138.

Torstensson, Bengt-Arne and Peterson, Andrew M. (1988), "A Hermetically Isolated Sampling Method for Ground-Water Investigations," Ground-Water Contamination: Field Methods, A.G. Collins and A.I. Johnson, Editors, ASTM, 1988, Philadelphia, Pa., pages 274-289.

Unwin, Jay and Maltby, Van (1988), "Investigations of Techniques for Purging Ground-Water Monitoring Wells and Sampling Ground Water for Volatile Organic Compounds," Ground-Water Contamination: Field Methods, ASTM, 1988, Philadelphia, Pa., pages 240-252.

USEPA (1986), RCRA Ground-Water Monitoring Technical Enforcement Guidance Document, Office of Waste Programs Enforcement, September 1986.

USEPA (1987), Handbook: Groundwater, EPA/625/6-87/016, 1987.

USEPA (1990), RCRA Orientation Manual 1990 Edition, Office of Solid Waste, EPA/530-SW-90-036.

Voytek, John E. (1983), "Considerations in the Design and Installation of Monitoring Wells," Ground Water Monitoring Review, Winter 1983, pages 70-71.

SUPPLEMENTAL BIBLIOGRAPHY

Acar, Y.B., Olivieri, I., and Field, S.D. (1985), "Transport of Organic Contaminants and Geotechnical Properties of Fine-Grained Soils," Proceedings of the Eleventh International Conference on Soil Mechanics and Foundation Engineering, ISSMFE, 1985, pages 1237-1240.

Bohn, Hinrich L., McNeal, Brian L., and O'Connor, George A. (1985), Soil Chemistry, Second Edition, John Wiley and Sons, New York, New York, pages 150, 187, 198-199, 241.

Chudyk, Wayne, Pohlig, Kenneth, Exarhoulakos, Kosta, Holsinger, Jean, and Rico, Nicola (1990), "In Situ Analysis of Benzene, Ethylbenzene, Toluene, and Xylenes (BTEX) Using Fiber Optics," Ground Water and Vadose Zone Monitoring, David Nielsen and A. Ivan Johnson, editors, ASTM, Philadelphia, Pa., pages 266-271.

Cline, Patricia V., Delfino, Joseph J., and Rao, P. Suresh (1991), "Partitioning of Aromatic Constituents into Water from Gasoline and Other Complex Solvent Mixtures," Environmental Science and Technology, Volume 25, no. 5, American Chemical Society, Washington, D.C.

Cooper, Stafford S. and Malone, Philip G. (1991), "Three-Dimensional Mapping of Contaminant Distribution in Soil Using a Soil Penetrometer," The Military Engineer, August, 1991, Society of American Military Engineers, Alexandria, Virginia, pages 54-55.

Daniel, David E. (1989), "In Situ Hydraulic Conductivity Tests for Compacted Clay," Journal of Geotechnical Engineering, ASCE, September 1989, pages 1205-1226.

Devinny, Joseph S., Everett, Lorne G., Lu, James C.S., and Stollar, Robert L. (1990), Subsurface Migration of Hazardous Wastes, Van Nostrand Reinhold, New York, New York.

Dunford, D., Brookman, J., Bilica, J. and Milligan, J. (1991), "LNAPL Distribution in a Cohesionless Soil: A Field Investigation and Cryogenic Sampler," Ground Water Monitoring Review, Summer 1991, pages 115-122.

Fenn, Dennis, Cocozza, Eugene, Isbister, John, Braids, Olin, Yare, Bruce, and Roux, Paul (1977), Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities, EPA/530/SW-611, August 1977.

Gillham, Robert W. and O'Hannesin, Stephanie F. (1990), "Sorption of Aromatic Hydrocarbons by Materials Used in Construction of Ground-Water Sampling Wells," Ground Water and Vadose Zone Monitoring, ASTM STP 1053, ASTM, Philadelphia, Pa., pages 108-122.

Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells (1991), EPA/600/4-89/034, March 1991, USEPA, Las Vegas, Nevada.

Heller, S.R. and Mine, G.W.A. (1978), EPA/NIH Mass Spectral Data Base, U.S. Government Printing Office, Washington, D.C.

Hillel, Daniel (1980), "Chapter 10: Movement of Solutes and Soil Salinity," Fundamentals of Soil Physics, Academic Press, New York, New York, pages 233-261.

Kerfoot, William B. (1988), "Monitoring Well Construction, and Recommended Procedures for Direct Ground-Water Flow Measurements Using a Heat-Pulsing Flowmeter," Ground-Water Contamination: Field Methods, ASTM, 1988, Philadelphia, Pa., pages 146-161.

Klopp, Rick A. and Walker, J. Michael (1987), "The Use of Cone Penetration Testing for Evaluation of Waste Disposal Alternatives," Geotechnical Practice for Waste Disposal '87, ASCE, 1987, New York, New York, pages 596-610.

Kostecki, Paul T. and Calabrese, Edward J. (1991) Hydrocarbon Contaminated Soils and Groundwater, Vol 1., Lewis Publishers, Chelsea, Michigan.

Kurtovich, Martin (1987), "Monitoring for Hazardous Waste Leaks: Saturated Zone Sensors," Civil Engineering, ASCE, February 1987, New York, New York, pages 48-51.

Leahy, Joseph G. and Colwell, Rita R. (1990), "Microbial Degradation of Hydrocarbons in the Environment," Microbiological Reviews, Vol. 54, No. 3, September 1990, American Society for Microbiology, Washington, D.C., pages 305-312.

MacKay, Donald and Shiu, Wan Ying (1981), "A Critical Review of Henry's Law Constants for Chemicals of Environmental Interest," Journal of Physical and Chemical Reference Data, American Chemical Society, Washington D.C., Vol. 10, No. 4, pages 1175-1198.

Mackay, Douglas, Roberts, Paul V., and Cherry, John A. (1985), "Transport of Organic Contaminants in Groundwater," Environmental Science and Technology, American Chemical Society, Vol. 19, No. 5, 1985, Washington D.C., pages 384-392.

Montgomery, John H. and Welkom, Linda M. (1990), Groundwater Chemicals Desk Reference, Lewis Publishers, Chelsea, Michigan, pages 30-33, 501-506, 547-551.

Noonan, David C. and Curtis, James T. (1990), Groundwater Remediation and Petroleum: A Guide for Underground Storage Tanks, Lewis Publishers, Chelsea, Michigan.

Nyer, Evan K. (1985) Groundwater Treatment Technology, Van Nostrand Reinhold Company, New York, New York.

Oweis, Issa and Khera, Kaj (1990), Geotechnology of Waste Management, Butterworths, London.

Petsonk, Andrew and Martens, Brett (1985), BAT Groundwater Monitoring System: Permeability Kit Instruction Handbook, BAT Envitech Inc., Long Beach, California, 1985, pages 1-49.

Petsonk, Andrew and Martens, Brett (1985), BAT Groundwater Monitoring System: Piezometer Installation Guide, BAT Envitech Inc., Long Beach, California, 1985, pages 1-20.

Petsonk, Andrew and Martens, Brett (1985), BAT Groundwater Monitoring System: Pore Pressure Kit Instruction Handbook, BAT Envitech Inc., Long Beach, California, 1985, pages 1-22.

Petsonk, Andrew and Martens, Brett (1985), BAT Groundwater Monitoring System: Sampling Kit Instruction Handbook, BAT Envitech Inc., Long Beach, California, 1985, pages 1-28.

Pettyjohn, Wayne A. and Hounslow, Arthur W. (1983), "Organic Compounds and Ground-Water Pollution," Ground Water Monitoring Review, Fall 1983, pages 41-47.

Peyton, R. Lee and Schroeder, Paul R. (1990), "Evaluation of Landfill-Liner Designs," Journal of Environmental Engineering, ASCE, May/June 1990, pages 421-437.

Rowe, R. Kerry (1987), "Pollutant Transport through Barriers," Geotechnical Practice for Waste Disposal '87, ASCE, 1987, pages 159-181.

Rowe, R.K., Caers, C.J., and Crooks, V.E. (1985), "Pollutant Migration through Clay Soils," Proceedings of the Eleventh International Conference on Soil Mechanics and Foundation Engineering, ISSMFE, 1985, pages 1293-1298.

Schowengerdt, R.W. (1987), "An Overview of Ground Water Monitoring Techniques," Detection, Control, and Renovation of Contaminated Ground Water, edited by Norbert Dee, William F. McTernan, and Edward Kaplan, ASCE, pages 38-50.

Sitar, Nicholas, Hunt, James R. and Udell, Kent S. (1987), "Movement of Nonaqueous Liquids in Groundwater," Geotechnical Practice for Waste Disposal '87, ASCE, pages 205-223.

Standard, David I. (1990), "Tensiometers--Theory, Construction, and Use," Ground Water and Vadose Zone Monitoring, ASTM STP 1053, ASTM, Philadelphia, Pa., pages 34-51.

Testa, Stephen M. and Winegardner, Duane L. (1991), Restoration of Petroleum-Contaminated Aquifers, Lewis Publishers, Chelsea, Michigan.

Thomas, Debra H. and Delfino, Joseph J. (1991), "A Gas Chromatographic/Chemical Indicator Approach to Assessing Ground Water Contamination by Petroleum Products," Ground Water Monitoring Review, Fall 1991, pages 90-100.

USEPA (1989), Transport and Fate of Contaminants in the Subsurface, EPA/625/4-89, CERL, Cincinnati, Ohio.

Verschueren, Karel (1983), Handbook of Environmental Data on Organic Chemicals, second edition, Van Nostrand Reinhold Company, New York, New York, pages 237-239, 1103-1106, 1188-1190.

Villaume, James F. (1985), "Investigations at Sites Contaminated with Dense, Non-Aqueous Phase Liquids (NAPLs)," Ground Water Monitoring Review, Spring 1985, pages 60-74.

Woeller, D.J., Weemes, I., Kolcan, M., Jolly, G., and Robertson, P.K. (1991), "Penetration Testing for Groundwater Contaminants," Geotechnical Congress, Boulder Colorado, June 1991, pages 76-87.

BIOGRAPHICAL SKETCH

Barry S. Mines was born in the Allegheny Mountains of Virginia in the small rural town of Hot Springs in July 1962. He attended Bath County High School and graduated as its valedictorian in 1980. At that time he accepted a 4-year Air Force ROTC scholarship to attend the Virginia Military Institute in nearby Lexington, Virginia, and to follow in the footsteps of his brother and brother-in-law who were graduates.


At the Virginia Military Institute he majored in civil engineering and was involved in numerous activities. These included being a member of the student chapter of the American Society of Civil Engineers, serving as a company commander in the Corps of Cadets, and, his greatest honor, serving two years on its Honor Court, first as an assistant prosecutor and then as its vice-president. While at VMI he became interested in geotechnical and environmental engineering. His classmates selected him to be valedictorian of the class of 1984. He received the school's award for environmental engineering and the American Society of Civil Engineering Award for the outstanding civil engineering graduate.

Upon graduation from VMI he married the former Wendy Leigh Dodson of Danville, Virginia, whom he had dated for five

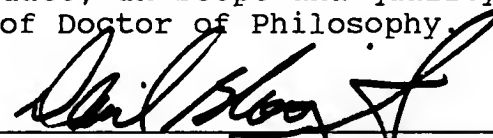
years. He then began graduate studies at the Virginia Polytechnic Institute and State University. He received a masters degree in civil engineering in December 1985 under the guidance of Dr. Wayne Clough and Dr. Mike Duncan.

He reported to active duty with the Air Force in February 1986. He served as a contract management engineer and a design engineer at Dover AFB, Delaware, until the summer of 1989. While at Dover he took and passed the professional engineer's examination, and his wife blessed him with the birth of a son, Evan. While at Dover he was selected for the Air Force Institute of Technology's Civilian Institution program. This program sent him to the University of Florida to obtain his Doctor of Philosophy degree in civil engineering before returning to active duty.

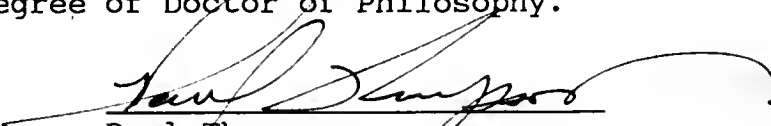
I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


John L. Davidson, Chair
Professor of Civil Engineering


I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


David Bloomquist, Cochairman
Assistant Professor of
Civil Engineering

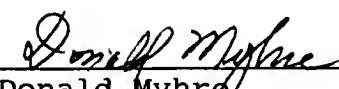
I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


Paul Thompson
Professor of Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

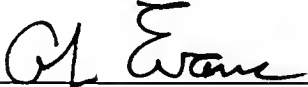

Frank Townsend
Professor of Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.


Donald Myhre
Professor of Soil Science

This dissertation was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August 1992

for 

Winfred M. Phillips
Dean, College of Engineering

Madelyn M. Lockhart
Dean, Graduate School

